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REFLECTIVE FLOOR FINISHES FOR AIRCRAFT MAINTENANCE HANGARS.(U)

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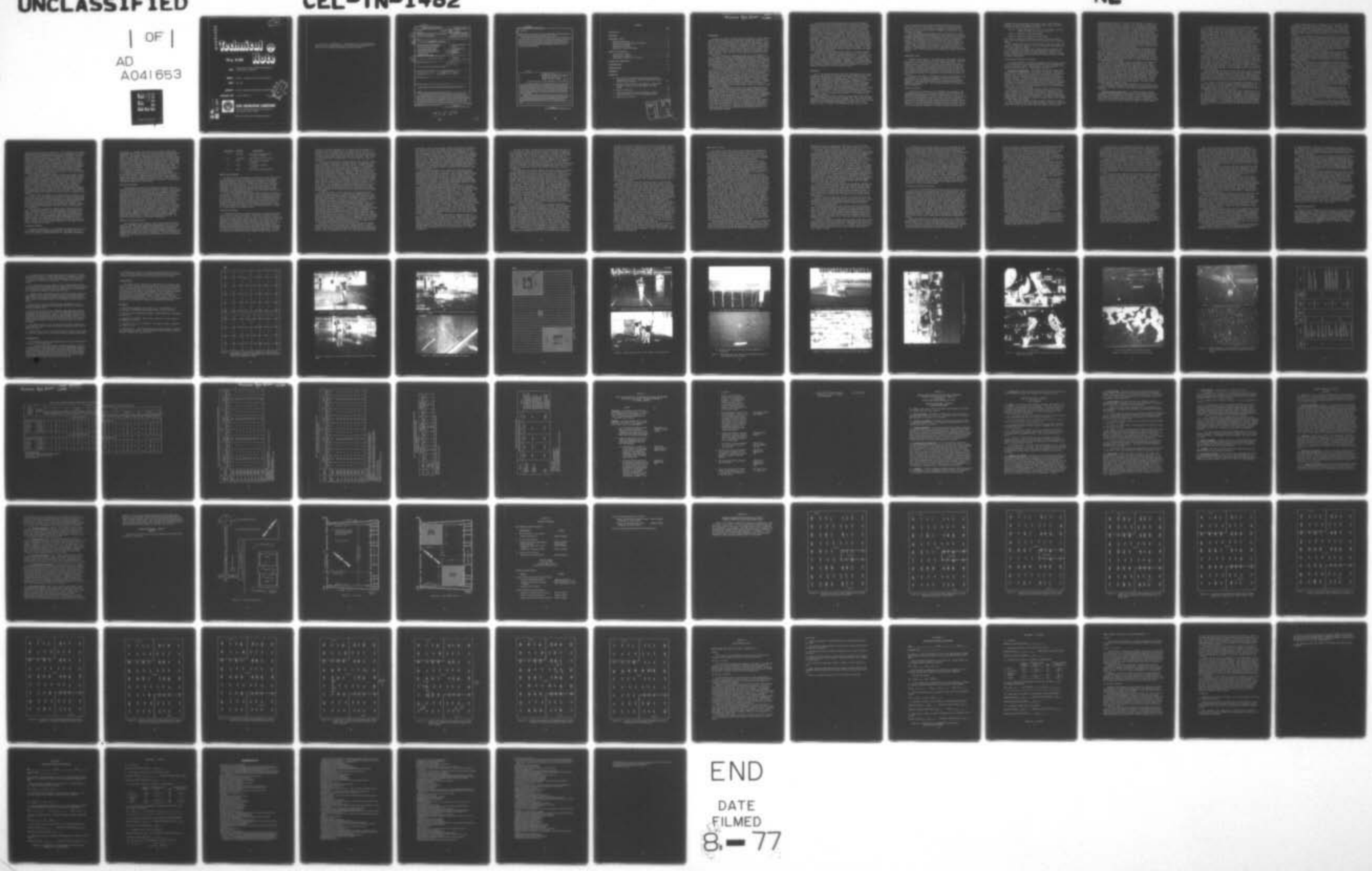

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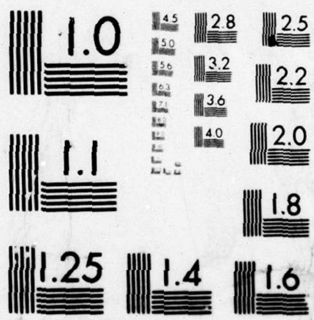

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Technical Note

TN no. N-1482

title: REFLECTIVE FLOOR FINISHES FOR AIRCRAFT MAINTENANCE HANGARS

author: Robert L. Alumbaugh, Ph D, and David Gurganus

date: May 1977

sponsor: NAVAL FACILITIES ENGINEERING COMMAND

program nos: YF53.534.007.01.011

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

101

REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TN-1482
2. GOVT ACCESSION NO: DN544221
3. RECIPIENT'S CATALOG NUMBER: 9 rept.
4. TITLE (and Subtitle): 6 REFLECTIVE FLOOR FINISHES FOR AIRCRAFT MAINTENANCE HANGARS.
5. TYPE OF REPORT & PERIOD COVERED: Final, Jul 1971–Aug 1975,
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): 10 Robert L. Alumbaugh, Ph D. and David Gurganus
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: CIVIL ENGINEERING LABORATORY, Naval Construction Battalion Center, Port Hueneme, California 93043
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62760N; YF53.534.007.01.011
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Facilities Engineering Command, 200 Stovall Street, Alexandria, Virginia 22332
12. REPORT DATE: 11 May 1977
13. NUMBER OF PAGES: 85
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 14 CEL-TN-1482
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): 12 83p.

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): 16 F53534 17 YF53534007
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Reflective finish, paint, aircraft maintenance hangars, hangar decks, illumination

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Results indicate that illumination levels underneath aircraft on the coated decks increased up to tenfold over the control deck. The increase is also indicated by results of human factors studies; aircraft maintenance personnel required less auxiliary lighting with the reflective-coated deck. A general preference was expressed by personnel for the reflective-coated deck. The chemically resistant urethane performance was superior to the two moisture-curing urethane systems.

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Civil Engineering Laboratory
REFLECTIVE FLOOR FINISHES FOR AIRCRAFT MAINTENANCE HANGARS (Final), by Robert L. Alumbaugh, Ph D, and David Gurganus
TN-1482 85 pp illus May 1977 Unclassified

1. Illumination improvement 2. Reflective floor finishes I. YF53.534.007.01.011

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INTRODUCTION

Although the science of modern lighting techniques is quite complex, much has been learned in recent years about methods and procedures to achieve the best illumination possible for a given type of work. Generally, it is no longer satisfactory to determine if illumination levels are proper merely by measuring the illumination directly in foot-candles (FC) with a light meter. A number of factors now require consideration, including the luminaries; their location relative to one another; the visual response of the eye under varying light and environmental conditions; the size, shape, and color of the enclosure; and various other related factors.

Specific illumination requirements given in the IES Handbook [1] are, in general, now given in ESI (Equivalent Sphere Illumination) foot-candles rather than the older conventional foot-candles. Calculation of ESI foot-candles is not merely a straightforward conversion of standard foot-candles but requires input of a number of different variables. For optimum visibility, it is now generally understood that work areas must be designed with good lighting system geometry and luminous environment.

Good balanced illumination is a necessity in most types of mechanical or electronic maintenance facilities to insure safety, to increase efficiency, to insure error-free work, and to increase comfort of maintenance personnel. This is particularly true in aircraft maintenance hangars where error-free maintenance is required for survival of flight personnel and their aircraft. During the past several years, numerous complaints of inadequate illumination have been received from Naval aviation mechanics working in maintenance hangars. In order to insure adequate illumination in such hangars, it has been necessary to supplement existing lighting with auxiliary lights, either floodlights or flashlights, or simply restrict maintenance activities to daylight hours to make use of sunlight.

Criteria for illumination in Naval Air Station (NAS) maintenance hangars, according to the Naval Engineering Command's (NAVFAC) Design Manual DM-4 [2] and the Department of Defense Construction Criteria Manual DOD 4270.1M [3], is that specified in the Illuminating Engineers Society (IES) Lighting Handbook [1]. Illumination levels recommended in this handbook for aircraft maintenance hangars was increased several years ago to 100 FC (standard recommended illumination levels for maintenance hangars have yet to be converted to ESI foot-candles). Since many of the hangars at Naval Air Stations are of older design, only those constructed very recently even approach this illumination level. In all probability, underaircraft maintenance illumination requirements were not even considered in the lighting design for the older maintenance hangars.

As increased illumination requirements for aircraft maintenance hangars were recognized, many NAS Public Works Departments considered submitting special projects to upgrade their existing lighting systems. Illumination under the aircraft, where more than 40% of all aircraft maintenance is carried out, still constitutes a problem because drab concrete floors and walls are not highly reflective surfaces, and much of the incident illumination is absorbed. Underaircraft illumination can be improved to a more acceptable level using several methods, none of which are completely satisfactory. Two of the most obvious methods, flashlights or floodlights, used as auxiliary lighting, have already been mentioned. Both of these have a potential hazard connected with their use. Flashlights can easily, but inadvertently, be left in the aircraft which can lead to mechanical failure during flight. Floodlamps frequently are mounted on carts and have their own gasoline engine driven power supply; these are noisy and emit noxious fumes in the hangar. If floodlamps are powered from outlets within the hangar, drop cords that supply power are easily tripped over.

Installation of flush-mounted floor lamps or a complete relamping of the hangar are two additional lighting alternatives. This first alternative is quite expensive even when installed in a new hangar under construction. Also, because of the particular type of illumination, the glare of such lamps can be blinding to maintenance personnel; in addition, these lamps cause harsh shadows. Relamping of an existing hangar, even where the incident illumination is significantly increased, provides only a minimal increase in light reflected up underneath the aircraft because of absorption of light by decks and walls.

BACKGROUND

All of the alternatives given above were considered by Public Works personnel at NAS Oceana, as they prepared plans for upgrading the illumination in the east barrel of Hangar 122. Hangar 122 is an older, conventional double-barrel maintenance hangar. Relamping of this maintenance hangar, which was the primary method under consideration for upgrading the illumination, would be designed to increase the average incident illumination from a level of about 45 FC to the recommended 100 FC. The estimated cost for this upgrading was $64,600 in 1970 dollars. It was mentioned earlier that upgrading of the incident illumination would provide only a small increase in illumination reflected underneath the aircraft. As a result, NAS Oceana considered yet another alternative – use of a reflective floor finish – to the underaircraft illumination problem.

NAS Oceana had conducted an informal investigation of white reflective floor finishes in a small area of Hangar 122. They found that when compared to an uncoated deck such a reflective floor finish could increase several fold the illumination underneath an aircraft [4,5]. As a result, in lieu of a project for relamping the east barrel of Hangar

122 they submitted a Research and Development Proposal to coat the hangar deck and walls (to a height of 7 feet) with a white reflective deck finish. Such an application was estimated at $16,000 (in 1970 dollars) giving a potential savings of $48,600 (in 1970 dollars) over relamping the hangar.

The Civil Engineering Laboratory (CEL) was requested by the Naval Facilities Engineering Command (NAVFAC) to assist its Atlantic Division (LANTDIV) and NAS Oceana in an investigation of reflective floor finishes for improving illumination levels underneath aircraft in maintenance hangars. The investigation was to be carried out by application of reflective floor finishes to the deck of the east barrel of Hangar 122, at NAS Oceana; the identical west barrel was to be left uncoated as a control. The investigation was not merely a coatings test but was designed to determine the actual benefits that might be derived by the Navy by virtue of using reflective floor finishes in aircraft maintenance hangars.

EXPERIMENTAL TESTS

Construction of Hangar 122 was completed in 1956 and thus had been in use about 16 years when the reflective finish was applied. The floor area of each of the high barrels is about 39,000 square feet. The lighting system is essentially the same in each barrel and consists of seventy-two 1,000-watt mercury vapor lamps mounted about 48 feet above floor level. A contract was awarded in 1964 to resecure the lamps to better withstand jet vibration and wind actions but this did not affect the luminance or locations of the lamps to any appreciable extent. The floor plan and location of the lamps for the east barrel are shown in Figure 1.

Because of the number of activities that were to participate in the investigation, a test plan was prepared that noted each activity's participation and was submitted to NAVFAC. The test plan is given in Appendix A. The construction contract specification was prepared by LANTDIV and reviewed by CEL. The technical portions of the contract are given in Appendix B.

Materials Selection

Selection of the reflective floor finishes to be included in the investigation was made on the basis of manufacturers' information and discussions among personnel from NAVFAC, LANTDIV and CEL. Since the purpose of the investigation was not to test a variety of coating systems but to determine benefits derived by the Navy when using reflective finishes, it was decided to limit coating selection to urethane systems such as those used by NAS Oceana during their earlier informal test in Hangar 122. The three reflective urethane floor finish systems included in the investigation consisted of two single package, moisture-curing

urethanes and one two-package, catalytically cured, highly abrasion resistant and chemically resistant urethane (CRU). Each of the three systems were given a designation as follows:

System A – Federal Specification TT-C-542, polyurethane, oil-free, moisture-curing, coating, Type II, white.

System B – Moisture-curing urethane (MCU)

System C – Chemically resistant urethane (CRU)

Each system consisted of a primer and two white, reflective-finish coats. Grit was sprinkled into the first wet topcoat to add a nonskid quality.

The concrete block walls of the east barrel of the test hangar were coated to a height of 7 feet with two coats of Federal Specification TT-E-489, white synthetic enamel.

Steel hangar doors (after proper cleaning) were spot-primed with Federal Specification TT-P-645 zinc chromate primer followed by two coats of TT-E-489 white synthetic enamel applied to a height of 7 feet. All specification coatings were analyzed to be sure that they conformed to their specification.

Preparation and Application Procedures

The Tennant Company of Minneapolis, Minnesota, was the prime contractor for application of the reflective finishes as well as manufacturer of two of the three systems. Refinishing of the walls and doors of the hangar was subcontracted to a local painting contractor.

Deck Surface Preparation. This hangar had been constructed about 16 years prior to application of the reflective finishes. During this interval, the concrete deck was subjected to spillage of materials that usually occurs in maintenance hangars such as oils, fuels, aircraft cleaners, thinners, and hydraulic fluids, many of which had penetrated into the concrete. In order to obtain proper bonding of the floor finishes, it was necessary to thoroughly clean and etch the hangar deck to remove all contaminants before application of the primers. Preparation of the deck surface for painting was carried out in essentially three steps: (1) paint and traffic marking removal, (2) oil and grease removal, and (3) concrete etching.

Paint from the small informal reflective finish test and from traffic markings was treated with a semipaste paint remover at the rate of 50 sq ft/gal to soften and lift the old paint. To facilitate the removal, most of the old, softened paint film was removed mechanically using a Tennant K-4 Industrial Floor Machine. The deck was then wetted, sprinkled with a small amount of industrial grease remover, and scrubbed to remove paint film residue.

The second step involved cleaning the entire hangar deck, area by area, with a cleaner, and curing compound remover. One part cleaner and remover was mixed with five parts high flash naptha solvent and the

mixture applied initially at the rate of 100 sq ft/gal. During this operation (shown in Figure 2), water was also applied to the deck. The cleaner and remover used was reported to be a chlorinated emulsifiable solvent that removed residual concrete curing compound and penetrated into pores and cracks of the concrete to remove oil and grease that had soaked into these areas over the years. In addition to the cleaner-remover/naptha mixtures, water and an industrial grease remover were sprinkled onto the deck (see Figure 3) after the cleaner-remover had set for about 20 minutes. The solid industrial grease remover was a highly alkaline, low phosphate, biodegradable detergent. This total mixture was then thoroughly scrubbed with both riding (see Figure 4) and hand-operated scrubbers which facilitated removal and emulsification of the oil and grease. The total mixture appeared to perform reasonably well, in that floating oil was noted on the wetted deck after these materials had set and was then emulsified when scrubbed.

This oil and grease removal phase was repeated as necessary; and, in a few of the areas, the operation was repeated a second and even a third time because the deck was not completely free of contamination. The total application rate of these materials used for oil and grease removal is obviously dependent on the degree of contamination of the deck. When the contractor was satisfied with the condition of the deck, it was thoroughly rinsed with clean water, scrubbed, vacuumed damp dry, and permitted to dry overnight.

In the final step a precoat cleaner was applied to the degreased concrete deck at a rate slightly higher than 100 sq ft/gal. This precoat cleaner or etching solution is a combination of mild organic acid, detergents, emulsifiers, and small amounts of solvent. It was applied to a dried floor so that it would penetrate into and open the surface pores of the concrete deck, thus giving a better surface for the reflective finish to bond to. After the precoat cleaner had soaked into the deck for 10 to 15 minutes, the deck was sprinkled with water and a detergent cleaner (a high-phosphate, nonresidue detergent). The deck was thoroughly scrubbed and all water and residue vacuumed. Finally, the deck was rinsed two times with clean water and all excess water vacuumed from the floor with the scrubber-sweeper. The entire deck-cleaning operation required 3 days.

The following morning, the deck appeared to be dry and, for a 16-year old, previously oil-soaked deck, appeared to be exceptionally clean (Figure 5). The deck was given a final power brooming and was ready to be primed.

Reflective Finish Application. All reflective finish systems, including the Federal Specification materials, were applied in strict conformance with manufacturers' directions. A detailed description of each system and its application is given in Table 1. Trade names and sources of the reflective finish materials are given in Appendix C. The location of each of the systems within the hangar is shown in Figure 6.

The system area coated first was System B, a proprietary, moisture-curing urethane. This system, with which the majority of the hangar deck was coated (27,400 sq ft), consisted of one coat of a two-component, penetrating, epoxy primer and two coats of a moisture-curing urethane finish. The two components of the clear epoxy primer were thoroughly mixed, and a white color coat mixed in at the rate of 1/2 pt/gal. The white color coat consisted of vehicle wetted white pigment concentrate which gave the clear epoxy a translucent white color and gave the applicators assurance they were achieving complete coverage.

After mixing with the color coat, the primer was permitted to stand for a 20-minute induction period and then applied by rollers. The primer was permitted to dry for 2 to 3 hours until it had reached the proper tacky stage prior to application of the first urethane finish coat. Because of the extremely high temperature during this application, the epoxy appeared to have set more rapidly than expected which could have affected the adhesion between the primer and first finish coat.

While waiting for the primer to dry, the first finish coat of clear urethane was thoroughly mixed with two pt/gal of white color coat pigment concentrate. Following a 20-minute induction period after mixing, the first finish coat was applied to the tacky primer by roller. While the first finish coat was still wet, grit for nonskid purposes was sprinkled onto the deck. As shown in Figure 7, the grit was broadcast with a grass seeder, and the applicator wore golf shoes to permit walking on the wet first finish coat with as little damage as possible. The primer and finish coat were permitted to cure overnight prior to application of the final finish coat.

The next morning, the final clear urethane finish coat was thoroughly mixed with one pint per gallon of white color-coat pigment concentrate and set aside for a 20-minute induction period prior to application by roller over the first finish coat. This final finish coat, although of lower pigment concentration than the first, gave sufficient hiding power to the system and also provided additional holding power for the nonskid grit.

As a result of the extremely high temperature and humidity, the reflective finish of System B exhibited pinpoint blistering all over the area. However, this was not considered a serious problem as far as coating performance was concerned. In fact, the small blisters added to the nonskid property of the coating system.

System A, the second area coated, used Federal Specification TT-C-542, an oil-free moisture-curing urethane system. As noted earlier, the urethane finish coat was analyzed for conformance to the specification. The analysis showed that this material conformed to the specification in all respects except for the isocyanate content which was slightly high. This nonconformance was discussed with the manufacturer and the NAVFAC coatings' specialist. It was decided that the high isocyanate content should not present any serious problems and the material was approved for use.

Federal Specification TT-C-542 requires use of the primer sealer recommended by the manufacturer of the finish coat. This was a clear, water-thin, penetrating, silane sealer for System A. The primer was applied with lamb's wool applicators rather than rollers. Because the primer was clear, it was somewhat more difficult to determine when the surface had been completely covered than with the materials containing pigments.

As soon as the primer was dry (in approximately 2 to 3 hours), the first finish coat of TT-C-542, thinned one to one with the manufacturer's recommended thinner, was applied by lamb's wool applicators (see Figure 8). While the first finish coat was still wet, grit was again broadcast onto the deck. However, at the suggestion of the Naval Safety Center, grit was sprinkled onto only one-half of the area of System A. Since urethane coatings have an inherent slip resistance, the grit was omitted from half of the area to determine if it was actually required for nonskid purposes (see Figure 6 for location).

After the first finish coat had dried for about 4 hours, this system was completed with a final, unthinned finish coat of TT-C-542. Because of the thinning of the first finish coat of TT-C-542, this system exhibited poorer hiding characteristics than System B. Also, because of the extreme temperature and humidity, this system exhibited pinpoint blistering.

System C, the final area to be coated and the second of the two smaller areas, was coated with a two-component, chemically resistant urethane (CRU). This system also consisted of one coat of primer and two finish coats; however, both the primer and finish coats were urethanes.

The two components of the CRU primer were thoroughly mixed, set aside for a 10-minute induction period, and then applied by roller. After the primer had cured about 4 hours, the two components of the first finish coat were thoroughly mixed, given a 10-minute induction period, and applied by roller. Prior to this application, it was noted that the primer developed not only numerous pinpoint blisters but also a few larger blisters up to 1/2 or 3/4-inch in diameter. These larger blisters were broken by the contractor using lamb's wool applicators to expose the concrete deck and coated over with the first finish coat. While the first finish coat was still wet, grit was sprinkled into one-half of the area (see Figure 6 for location).

By late afternoon, the first finish coat had dried tack-free. At that time, there was no further blistering observed other than the normal pinpoint size. However, the following morning, much of the System C area exhibited severe blistering, from pinpoint up to about 2 inches in size. Figure 9(a) gives an overview of the system while Figure 9(b) shows a closer view giving an indication of blister sizes and frequency in one of the areas (note cleaned and spot-primed areas on hangar door in Figure 9(a)).

The day that the CRU primer and first finish coat of System C were applied was one of the hottest and most humid that occurred during the entire application. Temperatures were in the high eighties and nineties,

and the humidity was generally above 70%. These conditions were largely responsible for the blistering problems, and the manufacturer currently does not recommend application of this material above 80°F. The high humidity caused a certain amount of moisture to be retained by the concrete deck, even though it appeared dry. The combination of high temperature and humidity caused both the CRU primer and first finish coat to skin over and retain a larger amount of solvent than normal. It is believed that the blistering resulted from reaction of the urethane with moisture, producing carbon dioxide and vaporization of entrapped solvents. The vapor pressures of these gases were greater than the adhesion of the system to the deck. The volatiles could not escape because of the premature skinning on the surface of the coating systems and hence caused the blisters to form.

The contractor immediately started to remove those parts of System C that were badly blistered. Because this particular urethane system was highly chemically resistant, it could not be removed with chemicals. It was necessary to remove the CRU mechanically which, because of its excellent abrasion resistance, was slow and tedious. This blistered floor finish was removed with floor belt sanders and a Tennant K-4 Scarifier. Figure 10 shows the CRU removal with the K-4 machine. Figure 11 shows the floor after it had been cleaned and was ready for recoating, 3 days later. Although not all of the CRU had been removed, that remaining was tightly bonded to the concrete deck. The scarified and sanded hangar deck provided an excellent surface for bonding of this system.

The CRU primer was applied to the cleaned deck and allowed to cure sufficiently. This was followed by application of the two finish coats with a sufficient drying period between coats to prevent the blistering problem from recurring. Grit for nonskidding was again sprinkled into the first wet topcoat of one-half of this area (see Figure 6). No serious problems developed during the reapplication. However, because of the high temperature/humidity conditions, pinpoint blistering was still observed.

After all three systems were applied, traffic marking lines were added. During application of the floor finishes, the concrete block walls were coated with two coats of TT-E-489 white alkyd enamel to a height of 7 feet. Similarly, the metal doors were all wire-brushed to remove any rust or other contaminants, spot-primed with TT-P-645 zinc chromate primer, and coated with two coats of TT-E-489 white alkyd enamel. Figure 12 is a view of the completed job except for line markings. (Aircraft were being returned prematurely to the hangar because of storm warnings in the area.)

Illumination Readings

A grid was established so that illumination readings could be taken in the same locations during each inspection. The hangar lamps were used as grid points or station points for the illumination measurements

(see Figure 1). Readings were taken of both incident and reflected illumination about 5 feet above the hangar deck using a Weston model 614 lightmeter. The lightmeter was held at arm's length to minimize any effect from the observer. Readings were taken in the test hangar (east barrel of Hangar 122) before the deck was coated, both with and without aircraft in the hangar, and initially both during the hours of daylight (approximately 1200 to 1500) and darkness (2200 to 0100). Later, readings taken during daylight hours were suspended because it became obvious that the most important illumination readings were those taken during the hours of darkness. No readings were taken without aircraft in the hangar after the floor finish was applied because the aircraft were returned to the hangar before this could be accomplished.

Illumination readings were taken in the coated test hangar at predetermined intervals (generally at inspection periods) of 0.5, 6, 9, 15, 24, and 36 months. Similar readings were taken in the adjacent hangar (west barrel of Hangar 122) after 36 months. These illumination readings for the various periods are given in Appendix D and are summarized and discussed later in this report.

Human Factors Studies

The Human Factors Studies were conducted by personnel from the Naval Safety Center, Naval Air Station, Norfolk, Virginia. The objective of these studies was to determine the effect of coating the hangar deck with reflective finishes on the attitudes and performance of hangar squadron personnel. Two such studies were conducted, the first about a month after the deck was coated and the second about 1-1/2 years after application of the reflective finishes. The first study provided a reaction from maintenance personnel who had worked in the hangar before and after the deck was coated. The second study provided the same information from maintenance personnel who had been in the original group and had thus worked on the coated deck for about 1-1/2 years, and from personnel who had since been assigned to the squadron in the test hangar but who had also worked previously in a hangar with an uncoated concrete deck. Questionnaires designed by personnel from the Naval Safety Center, LANTDIV, and CEL were used in the studies. The Naval Safety Center analyzed the results of the questionnaires using the Bonferroni CHI-statistics to check for statistical differences. The Naval Safety Center reports are included as Appendix E.

Reflective Finish Performance

The performance of the reflective floor finish systems was determined by a thorough visual inspection after periods of 0.5, 9, 15, 24, and 36 months. The floor finishes were inspected for such things as removal of the reflective systems by chemicals (loss of bond) or by scratching or scraping from the concrete deck (abrasion resistance), and gradual wearing away (also abrasion resistance). The three reflective systems were assigned performance ratings during each of the inspections. These were:

Designation	Meaning	Description
E	Excellent	Little or no deterioriation or loss of coating
VG	Very good	Very minimal loss of coating
G	Good	Less than 5% of coating removed
F	Fair	5% to 10% of coating removed
P	Poor	Over 10% of coating removed

RESULTS AND DISCUSSION

The objective of this investigation had several facets, but basically the intent was (1) to determine if the reflective floor finishes reflected additional light up underneath the aircraft to facilitate maintenance operation and (2) to determine the benefits to the Navy of using reflective floor finishes. If the increase in reflected light underneath the aircraft was found to be quite significant, it might eliminate or at least reduce the need for auxiliary lighting or the requirement at several Naval Air Stations that maintenance operations be carried out only during daylight hours.

A few of the potential benefits that might be derived by the Navy through use of reflective floor finishes include reduced aircraft maintenance times, a reduction in error counts, better housekeeping practices, and less chance of foreign object damage. While the investigation was not considered nor treated as a coatings test, performance of the floor finishes must assume some importance because the floor finishes must remain on the floor and intact for some minimum length of time or their use becomes completely infeasible from an economic standpoint. Results of the investigation are presented below.

Illumination Readings

Incident and reflected illumination readings were taken at predetermined intervals using a grid system. Each of the 72 lamps within the test or the control hangar was used as a grid point, and the illumination readings were taken directly under each lamp. Both incident and reflected illumination readings were taken approximately 5 feet above the deck. Initially, the readings were taken both during the daylight hours (about 1200 to 1500) and during the hours of total darkness (2200 to 0100). Readings taken during daylight hours were discontinued after the 6-month inspection period because it became evident that the reflected illumination levels were quite high even on an uncoated hangar deck. As might be expected, the illumination within a hangar during daylight hours is

as much, if not more, dependent on the character of the sunlight (i.e., whether the sun is shining brightly, or whether the sky is hazy or overcast), as on the quality of the lighting. This is not to say that a reflective floor finish would not be beneficial during daylight hours; it could be particularly useful when the sky is overcast. The raw data for the illumination readings taken at the grid points are given in Appendix D.

It became obvious early in the investigation that a direct comparison of individual illumination readings would not be significant other than to provide an indication of relative values. Probably the most perplexing problem here was the fact that, in spite of a considerable effort on the part of station Public Works personnel, it was never possible to obtain test hangar illumination readings with more than 79% of the lamps functioning properly. Generally, only 60 to 70% of the lamps were lighted and, at the last inspection when the reflective floor finish was 36 months old, only 43% of the lamps were functioning properly. Such a variation had a considerable effect on individual illumination readings. In some cases, individual bulbs were out while in other cases, the whole lamp fixture was missing or entire strings of lamps (8 lamps) were out because of shorts or other electrical problems. In still other cases, illumination readings diminished because of the age of the bulbs. Such problems were beyond the control of the station. Because of funding and personnel limitations, relamping of the hangar was contracted out and the contractor was reported fulfilling the terms of his contract.

In order to obtain a better comparison of illumination levels, particularly reflected light, the best approach appeared to be to use average illumination values expressed as average foot-candles per lamp. Thus, the raw data given in the tables in Appendix D have been reduced and summarized in Tables 2 through 5. These tables present averages of both incident and reflected illumination in foot-candles per lamp (FC/lamp) for the total hangar (designated as total), and for each of the three system areas coated with the three different reflective floor finishes and designated as areas A, B, and C (corresponding to Systems A, B, and C, respectively). In addition to the average illumination readings mentioned above for all of the hangars' grid points, readings were taken only underneath aircraft and were averaged. These data are presented in Table 4. To be able to better assess the importance of the illumination readings, the tables also contain data covering (1) the percentage of lamps that were out or missing and (2) the percentage of average incident illumination that was reflected. These data are given for the uncoated control hangars and for the test hangar at the various inspection periods and are discussed below.

Reference to Table 2, which lists daylight illumination readings before and after coating the hangar deck, illustrates why it was not considered necessary to take the daytime readings past the 6-month time period. Table 2 gives average incident and reflected light readings per lamp for the total hangar and for all of the grid points within a given

system area. Table 2 gives average incident and reflected illumination per lamp only for those grid points that were underneath an aircraft. Even in the latter case, the average reflected illumination for the uncoated hangar was 20 FC/lamp. The lowest average reflected illumination (12 FC/lamp) occurred in the uncoated hangar in the area designated as System A. This minimum average illumination is about twice as high as any of the average underaircraft reflected illumination readings taken at night. These tables do show that the reflective floor finish does increase the underaircraft illumination considerably during daylight hours, and it appears that use of these finishes could reduce the requirement for lights during periods of bright sunshine as well as provide a more than adequate amount of underaircraft illumination when the sky is overcast.

A much better indication of the value of the reflective floor finishes is given in Tables 3 and 4 which list average illumination readings taken during hours of darkness. Table 3 gives average incident and reflected illumination per lamp for the total hangar and for all grid points within a given system area. Table 4 gives the average illumination per lamp only for those grid points that were underneath some part of the aircraft. The average illumination readings in these two tables are listed for the uncoated control hangar deck and for the coated hangar deck after various periods of aging.

Results indicate that the reflective floor finishes do provide improved illumination underneath aircraft compared to the illumination reflected from an uncoated concrete hangar deck. The increase in average reflected illumination as shown in Table 3 was from 1 to 2 FC/lamp before painting to 10 to 12 FC/lamp within a couple of weeks after painting (as much as a tenfold to twelvefold increase). After 3 years of use, the average illumination per lamp was 3 to 4 FC (a twofold to fourfold increase over the uncoated hangar deck). It should be noted that this increase in the average intensity of the reflected light from the coated hangar deck resulted from an average incident illumination at the time that was only 43% as intense (7.5 FC/lamp) as the direct illumination in the uncoated hangar (17.2 FC/lamp). This reduction in direct illumination was due primarily to the fact that 57% of the lamps were either out or missing in the coated hangar while only 18% of the lamps were not burning in the uncoated hangar. If all lamps were functioning properly, the amount of reflected illumination in the coated deck hangar should be considerably higher.

As noted above, the average illumination readings per lamp are given in Tables 3 and 4, not only for the total hangar but also for each area coated with the three reflective finishes. This was done to determine if any of the three reflective finish systems had an appreciable effect upon the amount of light reflected. A study of both tables reveals no obvious trends; that is, none of the three reflective floor finishes appears to continually reflect either more or less light than the other two, taking into account the relative amounts of incident illumination.

The most important illumination data obtained during this study is given in Table 4. While the average incident illumination readings are not particularly significant, they are listed for purpose of comparison. These readings serve to indicate the location of the grid point relative to the aircraft; that is, if the incident average is less than the reflected average, then most of the incident readings were taken directly underneath the aircraft and in effect are a measure of the amount of light reflected from the underside of the aircraft. If the average incident illumination is significantly greater than the reflected illumination, this indicates that the incident readings were taken very close to the edge of the aircraft and thus were directly affected by incident illumination.

The same holds true with the average reflected illumination readings obtained underneath the aircraft (Table 4) as with the illumination readings when all 72 grid points are averaged (Table 3). That is, when the floor finish was new (age 0.5 month), underaircraft illumination in the hangar increased significantly after the reflective finish was applied compared to the same hangar (east barrel) before the deck was coated. Thus, the illumination reflected under the aircraft averaged just under 7 FC/lamp for the total hangar when the floor finish was new while the same readings before the hangar was coated averaged much less than 1 FC/lamp, a 15- to 30-fold increase. The underaircraft reflected illumination readings continued to average over 6 FC/lamp through the 9-month inspection, after which it dropped to between 3 and 4 FC/lamp. Although 3 to 4 FC is not an exceptionally high intensity illumination, it does permit accomplishing much of the underaircraft maintenance without use of auxiliary lighting. During the final inspection (coating age 36 months), the reflected illumination had dropped to an average of only 2 FC/lamp. However, this was almost twice that of the adjacent west barrel of control hangar C-2 (average 1.4 FC/lamp) even though the average incident illumination in the coated hangar was only 43% as great as that in uncoated control hangar C-2.

It should be noted that the percent of incident illumination reflected underneath the aircraft presented in Table 4 was calculated by dividing the average reflected illumination in Table 4 by the average incident illumination for the same time period per hangar area from Table 3. As mentioned earlier, the average incident illumination values given in Table 4 are not particularly significant, and the amount of light reflected underneath the aircraft is more dependent on the actual incident illumination within the hangar. The percent reflected column for the total hangar shows that, except when the reflective floor finish was new, the coated deck normally reflects between 20 and 30% of the incident illumination up under the aircraft. This same column shows that in the hangar with an uncoated deck, only about 8% of the incident illumination is reflected to the underside of the aircraft. Based on these percentage figures, if the incident illumination in a hangar with a reflective floor finish were maintained at a minimum of 25 FC, one could expect an illumination level of 5 to 8 FC/lamp under the aircraft.

The average reflected illumination given for the total hangar in Table 3 included, and in Table 4 resulted from, 10 to 20 illumination readings taken at grid points underneath the aircraft. Since the grid points often fell at various points underneath the aircraft and might, therefore, give average reflected illumination values that were not totally representative, up to 10 additional reflected illumination readings were taken at the 24- and 36-month inspection periods. These readings were taken in one of two or three locations under the aircraft away from grid points, generally either directly under the center of the fuselage, or at the center of the wing where it connects to the fuselage. The average of the reflected illumination readings in each case was essentially the same as the values for the total hangar average reflected illumination given in Table 4. Figure 13 shows side-by-side photographs of similar aircraft, one in the west barrel of Hangar 122 with the uncoated concrete deck, and the other in the east barrel of Hangar 122 in which reflective floor finishes had been applied. The photographs, taken during the 24-month inspection period used the same film, the same exposure, existing light in the two hangars, and were developed and printed under identical conditions. It is believed that these two photographs document very well the value of the reflective floor finishes in reflecting light up underneath the aircraft.

As with the three system areas given in Table 3, the reflected illumination readings in Table 4, when tabulated according to system areas, show no obvious trends which might indicate that one of the three floor finish systems reflect light better than either of the other two.

Except when the floor finish was new (0.5 month), the coated deck of the test hangar was generally soiled when it was inspected and when illumination readings were taken. As a result it was uncertain whether or not the soil had any gross effect upon the reflectivity of the floor finish. During the 24-month inspection, readings were taken one night, and the station was requested to have the coated hangar deck cleaned the following day so that comparative light readings might be taken.

Actually, less than half of the floor area was cleaned, but the cleaned area included all of System A and about 45 percent of System B. The remainder of System B and System C were not cleaned. Cleaning was accomplished in the normal fashion by the men using a detergent and swabbing the painted deck. The deck was subsequently flushed with clean water and squeegeed as dry as possible. Raw data readings for the two 24-month inspections are given in Appendix D; averages are summarized in Table 5. Unfortunately, aircraft were considerably fewer in number and were not placed in the same locations for the illumination readings taken after the deck had been cleaned. As a result the values given in Table 5 represent average illumination readings for all of the grid points within the cleaned portion of the hangar. It was not possible to present underaircraft illumination values separately.

A study of the data in Table 5 indicates a very slight increase in incident illumination after cleaning which quite possibly could be attributed to fewer aircraft being in the hangar after cleaning. Thus, a completely clean deck does not appear to cause a significant change in the reflected illumination.

Human Factors Studies

The purpose of the human factors studies which were conducted by the Naval Safety Center, was to determine the effect of the reflective floor finishes on work procedures, patterns, and safety of aircraft maintenance personnel assigned to the test hangar. This was to include an assessment of required maintenance times, use of auxiliary lighting, and time required for normal deck cleanup and maintenance.

Questionnaires were distributed to Attack Squadron VA-42, the permanent squadron of the three assigned to the east barrel of Hangar 122, on two separate occasions. The first questionnaire was given to 101 aviation maintenance personnel about 1 month after the reflective finishes were applied. The second questionnaire was administered to 72 aircraft maintenance personnel of the same squadron about 1-1/2 years following coating of the deck. The questionnaires were supplemented by interviews with maintenance supervisory personnel.

The first survey provided a direct comparison of the effect of coated versus uncoated decks on work habits and attitudes since maintenance personnel had performed their function on both surfaces within the previous 3-month period. The second survey was a follow-up of the first study to determine if attitudes or work patterns had shown any significant changes in the interim. The report of the results of both of these Human Factors Studies received from the Naval Safety Center are given in Appendix E. The questionnaire that was administered to each of the two groups is a part of their report and gives a compilation of the responses for each of the studies. Since the questionnaire had been distributed to personnel on the day, evening, and midnight shifts, the Bonferroni-CHI square statistic was used to analyze the responses. This showed that the responses were not dependent on the shift except for question 2; that is, ''When performing maintenance on an aircraft in a hangar with a reflective coating, do you normally require auxiliary lighting?'' In this case, responses for both the day and midnight shifts were similar but significantly different from the responses from the evening shift. For the combined day and midnight shifts, 57% indicated a need for auxiliary lighting when working in a hangar with a reflective finish; 65% of the evening shift indicated they did not require auxiliary lighting. While two-thirds of the total group (all three shifts) indicated a need for auxiliary lighting on an uncoated hangar deck, only half of the total group indicated such a need on a deck with a reflective finish. Of those requiring auxiliary lighting on a coated hangar deck, 65% required less auxiliary lighting. Thus, of the total group, over 80% indicated that they required either less or no auxiliary lighting at all on a hangar deck with a reflective finish.

Unfortunately, maintenance times or error counts were not maintained for specific maintenance activities by the squadron. Because of this, it was not possible to obtain a quantitative comparison of these requirements before and after coating the hangar deck. Qualitatively, on the basis of the survey, about 40% of the maintenance personnel felt that

maintenance times were changed after the deck was coated while 60% indicated no noticeable difference. Thus, while there is an indication of some change, there is no clear-cut evidence on this point.

Two other important aspects included in the survey were deck cleaning procedures and the relative nonskid characteristics of coated versus noncoated hangar decks. Shortly after the deck was coated, LANTDIV, Public Works, and squadron personnel held a meeting to establish a cleaning schedule for the coated decks. One squadron (using 3 bays) stated that they cleaned the decks every Friday morning prior to inspection. A second squadron with 4 bays was not concerned about floor cleaning, while the third squadron, which occupied about half of the hangar, was to clean irregularly on an ‘‘as needed’’ basis. The intent was for CEL, LANTDIV, and Public Works to monitor relative requirements of the cleaning operations (compared to an unpainted hangar). However, because of the operational tasks of the squadron which had first priority, squadrons were not able to maintain their schedules; thus, monitoring and evaluating deck cleaning procedures and schedules developed into a hopeless effort. As a result, most of the information on this was obtained through the Human Factors Studies. Results of the first survey indicated that a regular uncoated hangar deck was in general easier to keep clean routinely. However, the coated concrete deck was judged easier to clean following a fluid spill.

From the standpoint of skid resistance or preventing slipping, the survey pointed out the following. First, water spills are more easily seen on an uncoated concrete deck, while oil, fuel or hydraulic fluid spills are more easily seen on a coated deck. The fact that water is difficult to see on a coated deck does present a definite hazard. It was the opinion of the group that when wet or oily, a coated concrete deck, either with or without grit, was harder to walk on than a plain concrete deck.

Finally, the white reflective coatings on the deck and walls did not appear to cause any undesirable glare. In spite of the floor cleaning problems and the various problems associated with slipperiness of the reflective finishes, maintenance personnel expressed a general preference for the coated deck.

The second questionnaire was also administered to Attack Squadron VA-42. Only personnel who had filled out the first questionnaire and those with previous maintenance experience on regular uncoated concrete decks were surveyed. The study again included personnel in all three shifts. Responses were again analyzed using the Bonferroni-CHI statistic to determine if there was any statistical differences between responses from the three shifts and if there were significant differences between the two surveys.

Responses of those of different shifts showed no significant differences. However, there was a significant change between the two surveys regarding the ease of cleaning the decks. Personnel in the first survey judged uncoated concrete decks easier to clean while those included in the second survey indicated that the coated concrete decks were, in fact, easier to clean.

As pointed out in the study report, it is quite possible that the first group preferred the plain concrete decks merely because they were used to working on them. Another possibility is that the cleaning routine for coated decks became essentially the same as that for uncoated concrete deck and because spills were judged easier to clean from a coated deck. The coated decks were considered easier to clean overall.

Responses to all other factors in the second survey were about the same as for the first. In both cases, strong concern was expressed about the potential slipperiness of the coated deck. A review of dispensary records for 1-1/2 years prior to application of the reflective finish and for 1-1/2 years afterwards, showed no reports of injury. Whether this is because there is no difference in nonskid characteristics between coated and uncoated decks or whether maintenance personnel are merely more careful on a coated deck is not known. Safety officers from the squadron have indicated that personnel have slipped and fallen but that none of these have been extremely serious. Psychologically, a glossy-coated deck seems more slippery to most people whether it has grit added for nonskid purposes or not. It may be that this psychology tends to make personnel more safety conscious and cautious. There is no doubt in the authors' minds, however, that a coated deck covered with an oil or water spill is, in fact, somewhat more slippery than the same materials on an uncoated concrete deck.

Performance of Reflective Finishes

All three of the reflective floor finish systems performed at least relatively well over the 36-month period of this investigation. The performance ratings assigned during the visual inspections are given in Table 6. A study of the results in this table indicates that the moisture-curing urethanes (Systems A and B) were still in relatively good condition after 3 years of hard use. These two systems are subject to removal by scratching and scraping from heavy equipment dragged across the deck (see Figure 14a), gouging by tools that are dropped and loss of bonding by chemical spill (see Figure 14b). However, these forms of deterioriation have not, with one exception, been considered extremely serious to date. The one exception occurred in the System B area in the southwest portion of the hangar. The amount of reflective finish that was being removed through usage during the first 6 to 8 months was considered excessive. Because of this, the contractor returned when the deck finish was about 9 months old and refinished about 4,500 square feet of this area as well as making minor spot repairs throughout the hangar.

Where the coating had lost bond in this large area of System B, the problem appeared to be lack of adhesion between the first finish coat and the epoxy primer. The lack of adhesion did not appear to be caused by oil or other spilled fluids that had saturated the deck over the past years but rather was attributed to the high temperatures during the application which caused the epoxy primer to cure too rapidly. The

primer was beyond the tacky stage when the first finish coat was applied and this affected the bonding of the first reflective finish coat. The contractor removed the coating system in this area either down to the concrete or at least to the primer and completely reapplied the total system; i.e., one coat of primer and two coats of moisture-curing urethane with grit applied to the first wet finish coat. The second application performed considerably better than the first, although this area of System B has exhibited poorer adhesion characteristics than most of the reflective finishes in other parts of the hangar.

The only other maintenance carried out on the reflective finishes was in the System A area. As noted previously, both Systems A and C areas were divided in half so that half of each system incorporated grit while the other half did not. It is interesting that while numerous complaints were received concerning the slipperiness of the nongrit portion of System A, no complaints were received by the project scientist concerning the absence of nonskid grit in one-half of System C area. The reason for this may be because the finish coat of System C exhibited more inherent skid resistance than System A. Perhaps more important, System A had a much glossier surface than System C.

Because of the potential problem, the nongritted area of System A was recoated 12 months after the original application. This process consisted of chemically cleaning the surface to remove all contamination, mechanically abrading (sanding) the existing finish coat to provide a better bonding surface, and applying two coats of the same moisture-curing urethane as that used in System B. Although grit was broadcast into the first wet topcoat during this repair, it was applied very unevenly. As a result, there are still some small patches that do not have nonskid grit. Because of this repair, this area of System A is currently in somewhat better condition than much of the System B area. While there have been some problems in this new coating bonding to the old in the System A area (see Figure 15), this is considered very minor at this time. In addition to the above, one other very noticeable difference in the systems is the yellowing and staining of the moisture-curing materials (Systems A and B). The chemically resistant urethane (CRU) retained its whiteness very well which is due not only to its nonyellowing characteristics when exposed to sunlight, but also to its excellent chemical resistance which inhibits staining. Also, because of this chemical resistance, the CRU has been virtually unaffected by chemical spills, and no loss of bonding has resulted.

The CRU has exhibited by far the best performance of the three systems included in the investigation. In addition to its excellent chemical resistance, this system exhibited excellent abrasion resistance and bonding characteristics. The CRU has been removed only in very small spots where heavy equipment has been dragged across the deck or dropped. Such coating damage often resulted in the concrete surface of the deck being gouged or otherwise removed.

After 36 months, the performance of System C is rated as very good to excellent while the two moisture-curing urethanes, Systems A and B, are rated good. On the basis of these results, it is estimated that the moisture-cured urethane systems may require extensive maintenance or a complete recoating after exposures of 4 to 6 years. It appears that the CRU system will easily perform very well for 6 years and may well last up to 10 years before extensive maintenance or coating is necessary.

In spite of the performance of these reflective systems, all of them exhibit one common problem. That is, loss of nonskid grit that is crushed and removed from the floor system when heavy equipment is dragged or rolled across the deck. This loss of grit seemed to occur at approximately the same rate in all three systems. A typical condition is shown by a photomacrograph (Figure 16) of a reflective finish 2 years old, where the larger dark spots are in effect holes in the coating where the grit has been removed. This certainly reduces the nonskid character of the deck.

It is believed that, where the coating has been abraded or scraped from the concrete in small spots, such spots could be easily cleaned and patched by squadron or Public Works personnel. The manufacturer of Systems B and C has indicated that such kits could be made available for patching although they are not available currently. If these areas remain bare for extended periods of time, it not only becomes more difficult and expensive to clean up prior to recoating, but also spillage penetrates into the concrete deck and adversely affects the adhesion of the coating system around the periphery of the bare area. Thus, the preventative maintenance suggested above not only would extend the life of a reflective deck but also should minimize surface preparation that would be required prior to completely recoating a hangar deck.

Results of this study show that the reflective floor finishes do perform a number of valuable functions. Many of these functions are included in categories that are extremely difficult to place price tags on. First, and probably most important, they do reflect additional illumination up underneath an aircraft, from two to ten times as much illumination as reflected from an uncoated concrete deck. Although the amount of illumination reflected underneath the aircraft was low after 3 years of use, it must be emphasized that the low values resulted from very low levels of incident illumination. If the amount of auxiliary lighting required is based on the relatively low level of incident illumination (i.e., 7 to 15 FC), then an increase in the incident levels toward the recommended 100 FC should result in a substantial increase in the underaircraft illumination and a substantial decrease in the amount of auxiliary lighting required. On the basis of the percentage of incident illumination reflected underneath the aircraft (20% to 30%), 100 FC of incident illumination should result in as much as 20 to 30 FC of illumination underneath the aircraft.

While it was not possible to obtain a quantitative measure of maintenance times before and after application of the reflective floor finishes, results of the Human Factors Studies did indicate that there was, in fact, a potential decrease in these times. In addition, use of the reflective floor finishes have two other probable benefits. First, they contribute to potentially less foreign object damage (FOD) to the aircraft. This is the case because objects are much more visible on a white than on a drab concrete deck. While the reflective floor finishes do constitute an original cost as well as a continuing maintenance cost, such costs are quite minimal compared to the loss of an aircraft because of foreign object damage.

Similarly, because tools and parts that have been dropped are much more visible on coated than on uncoated concrete, maintenance times may well be reduced. Also, because of this increased visibility, objects strewn around the hangar are much more obvious. Thus, these reflective decks contribute to better housekeeping practices which result in a safer working environment for maintenance personnel.

The Human Factors Studies also indicate that not only are fluid spills more easily seen on coated hangar decks, they are also easier to clean up from coated than from uncoated concrete decks. This should result in less time required hence a lower cost for cleaning such spills from a coated deck. It appears currently that routine cleaning procedures for the coated deck are not a great deal different than the cleaning procedure used for an uncoated concrete deck. The decks coated with white reflective finishes do, however, show evidence of being soiled or dirty to a much greater extent than an uncoated deck. Commands must be willing to accept this fact.

Finally, maintenance personnel appear to favor the coated decks and it is believed that this results in increased morale and a greater *espirit de corps*. This is pointed out by the fact that a new hangar, Hangar 404, constructed at NAS Oceana, following initiation of the reflective floor finish study, was coated with the CRU reflective finish as a direct result of the favorable response from maintenance personnel in the test hangar. Obviously, it would be quite difficult - if not impossible - to place a dollar savings that could be achieved through the use of these materials.

Cost is always an important factor and once a hangar deck is coated with a reflective finish, such a finish must be maintained. Thus, both the original cost and continuing maintenance costs must be considered if reflective finishes are to be utilized. According to the manufacturer, material and application costs for the CRU currently varies from $0.50 to $0.75/sq ft. This breaks down to about $0.25/sq ft for materials and $0.25 to $0.50/sq ft for cleaning and application costs. Use of one of the moisture-curing urethanes would probably reduce the cost about $0.10 to $0.12/sq ft, because of lower material costs.

The chemically resistant urethane (System C), one of the moisture-curing urethanes (System B), and the deck cleaning materials used are available from the manufacturer on a Navy Small Parts Contract

No. N00600-76-D-0947. Activities considering the reflective floor finishes may find it advantageous to purchase these materials via this Navy contract and then prepare and let a construction contract for their application. Such a procedure was employed for coating the deck of Hangar 404 at NAS Oceana.

The CRU was applied to the deck of Hangar 404, NAS Oceana immediately following its completion but prior to squadrons moving into the hangar. Since the hangar was new, the problem of cleaning an old oil-soaked deck was not of concern. However, coating of the hangar deck was not a part of the original hangar construction project but was carried out as a separate effort. The concrete deck of Hangar 404 was treated with a concrete sealer/hardener as part of the original construction contract. It, thus, was necessary to remove the sealer/hardener prior to application of the CRU.

Although the reflective finish in Hangar 404 is not a part of this investigation, information has been gained from that work that is worthy of note. That is, the CRU in Hangar 404 was not performing as well after 1 year as the CRU in the test hangar after 3 years. The CRU in Hangar 404 had lost adhesion and peeled in a number of small areas (mostly 1 square foot or less). This is not to say that this coating system is performing poorly in the new hangar; this is not true. It merely is not performing as well as in the test hangar.

It is believed that this difference in adhesive character may be a result of the difference in surface preparation between the two hangars. Because of the blistering problem when the CRU was first applied in the test hangar, the concrete deck was well-roughened during its removal. This roughened surface provided an excellent substrate for bonding of the CRU. The new hangar floor, on the other hand, may not have been thoroughly cleaned of all concrete sealer/hardener compound, which could adversely affect the adhesion of the CRU to the concrete. It is believed that a light machine sanding to remove any residual sealer/hardener might be most beneficial, in such a case, in improving the bonding characteristics of the CRU to the concrete deck.

FINDINGS AND CONCLUSIONS

1. Reflective floor finishes applied to the deck of an aircraft maintenance hangar provides a twofold to tenfold increase in reflected illumination underneath the aircraft compared to an uncoated hangar deck. Based on the percentage of incident illumination that was reflected up underneath the aircraft in this investigation it appears that underaircraft illuminations of 20 to 30 FC might be achieved using the reflective finishes if the incident illumination levels of 100 FC, as recommended in the IES Handbook are obtained.

2. Approximately 80% of the maintenance personnel included in a Human Factors Study indicated a reduced requirement or elimination of the need for auxiliary lighting when conducting maintenance on the underside of an aircraft on a hangar deck coated with a urethane reflective floor finish.

3. Less foreign object damage (FOD) and better housekeeping practices should result when a reflective finish is used because of greater visibility of objects on hangar decks and along hangar walls, but coated decks will show greater evidence of being soiled or dirty.

4. It appears that a coordinated system of properly designed luminaries and a CRU reflective finish on hangar decks and a reflective finish on hangar walls could provide satisfactory underaircraft illumination at lower incident illumination levels, thus providing an overall savings in energy.

5. On the basis of the Human Factors Study, there appears to be a general preference among aircraft maintenance personnel for reflective finishes on hangar decks.

6. The data do not indicate any consistent significant differences in illumination reflected from any of the three reflective floor finishes included in the investigation. However, the chemically resistant urethane (CRU) investigated performed in an overall manner superior to the moisture-curing urethanes and the CRU should give from 6 to 10 years of service before requiring recoating if the applied systems are properly maintained.

7. Grit applied as part of the reflective floor finish to impart non-skid character, tends to crush and be removed within the first 18 to 24 months of service.

8. Fluid spillage, such as jet fuel and hydraulic fluid, is much easier to see and to clean up on a coated deck than on an uncoated hangar deck.

RECOMMENDATIONS

On the basis of results obtained during the course of this investigation, it is recommended that:

1. Chemically resistant urethane systems be applied as a reflective finish to the decks (and walls) of aircraft maintenance hangars on a selective basis. The requirement for such finishes should be determined on an individual basis, and application should follow only where they would be of significant benefit to the Navy. This would probably include most hangars servicing fixed wing aircraft but would probably not be required in hangars servicing only helicopters.

2. Consideration be given to reducing recommended incident illumination levels to conserve energy and coordinating well-designed lighting systems to include luminaries and reflective deck and wall finish systems.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to personnel at NAS Oceana for their valuable assistance during the course of this investigation. In particular, Mr. Richard Phelps of the Public Works Department who proposed the work and was most helpful; Chief James Pelchat, also of the Public Works Department, for taking many of the illumination readings; and the personnel of Attack Squadron VA-42 for their cooperation. Appreciation is also extended to LCDR C.E. Sandler, Navy Safety Center, for conducting the Human Factors Studies, and Mr. Harry L. Ammlong, Coatings and Chemical Laboratory, U.S. Army Aberdeen Research and Development Center for arranging for analysis of specification coatings.

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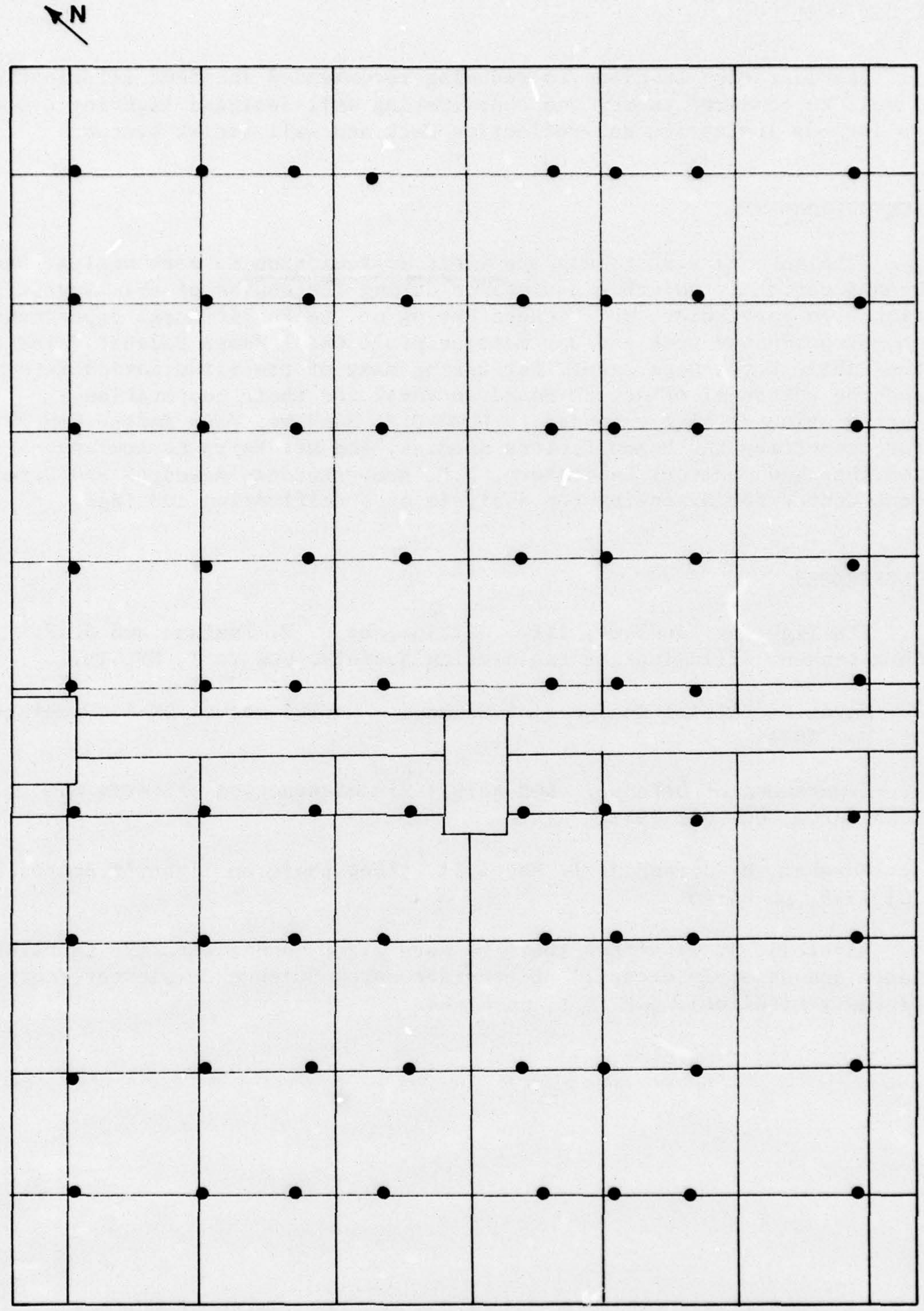


Figure 1. Floor Plan of east barrel of Hangar 122. (Dots indicate approximate location of lamps relative to joints in concrete which are represented by lines.)

Figure 2. Application of cleaner-remover high flash naptha solvent to deck to remove grease and oil.

Figure 3. Application of water and industrial grease remover to hangar deck.

Figure 4. Hangar deck thoroughly scrubbed during the grease removal phase.

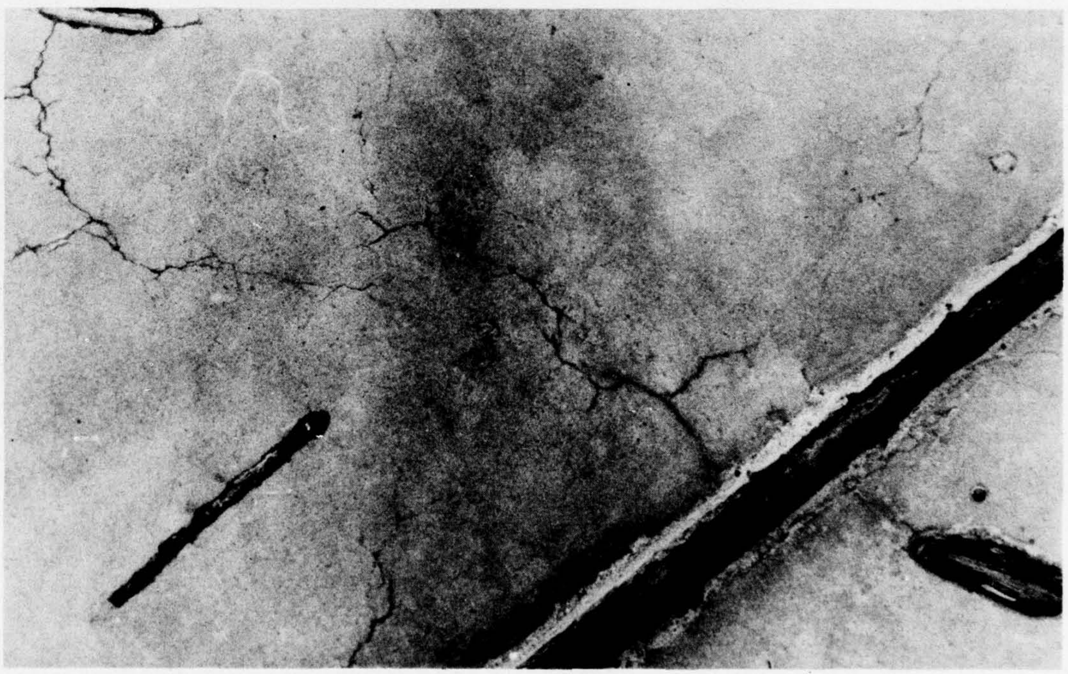


Figure 5. Condition of cleaned deck ready for priming.

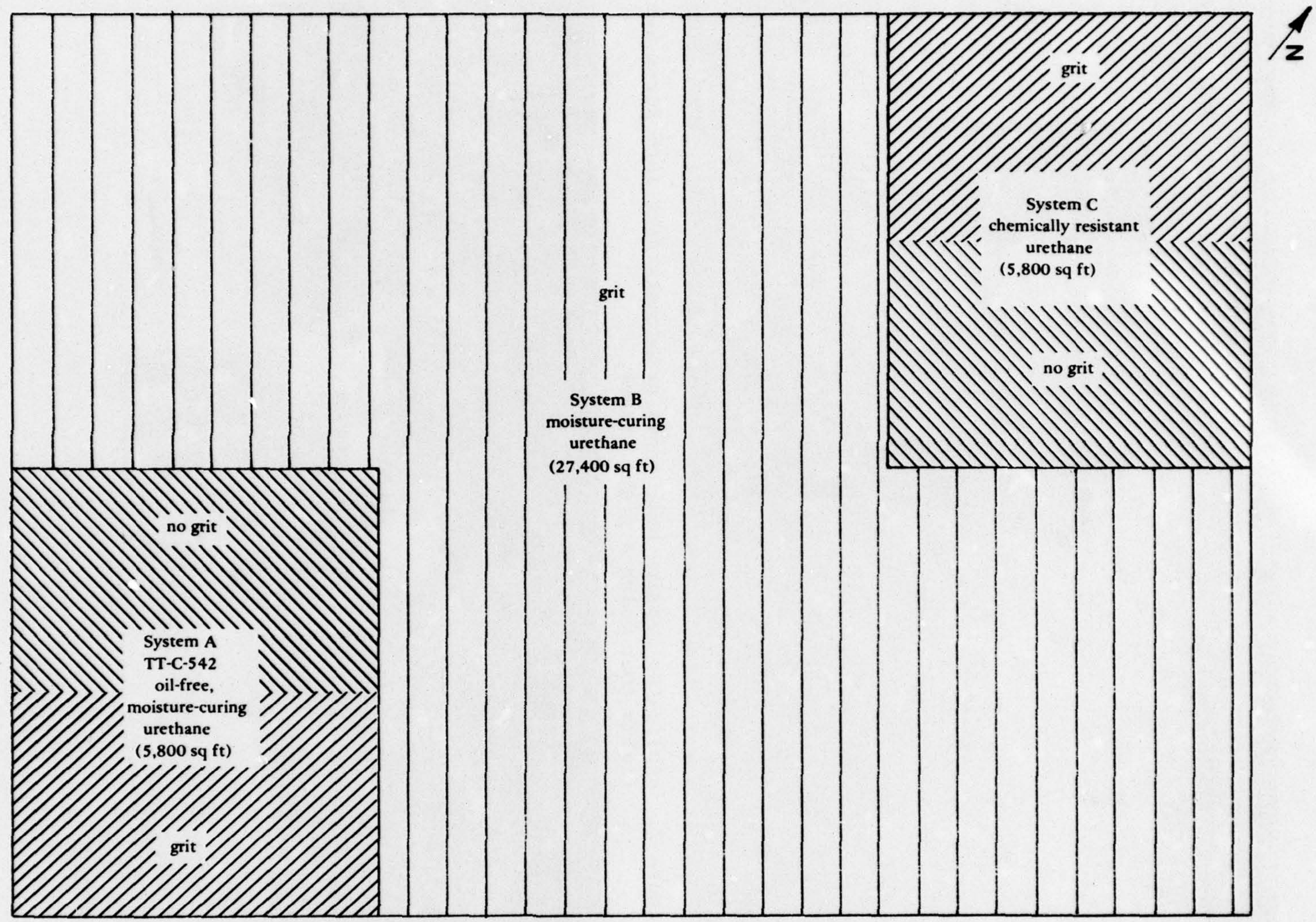
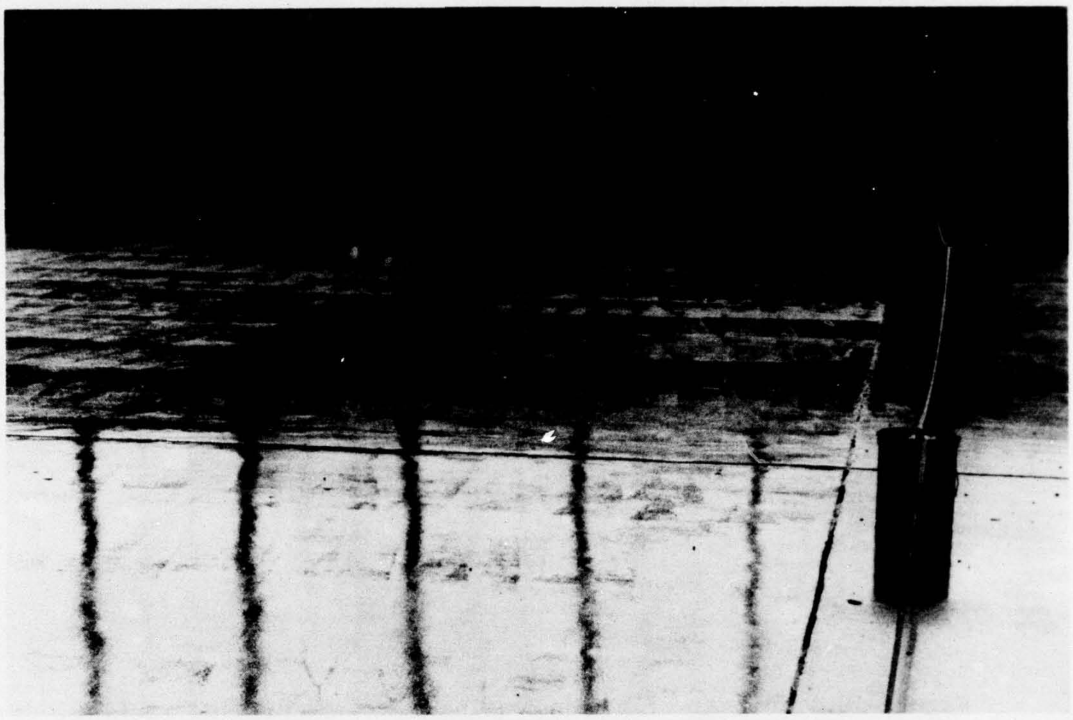


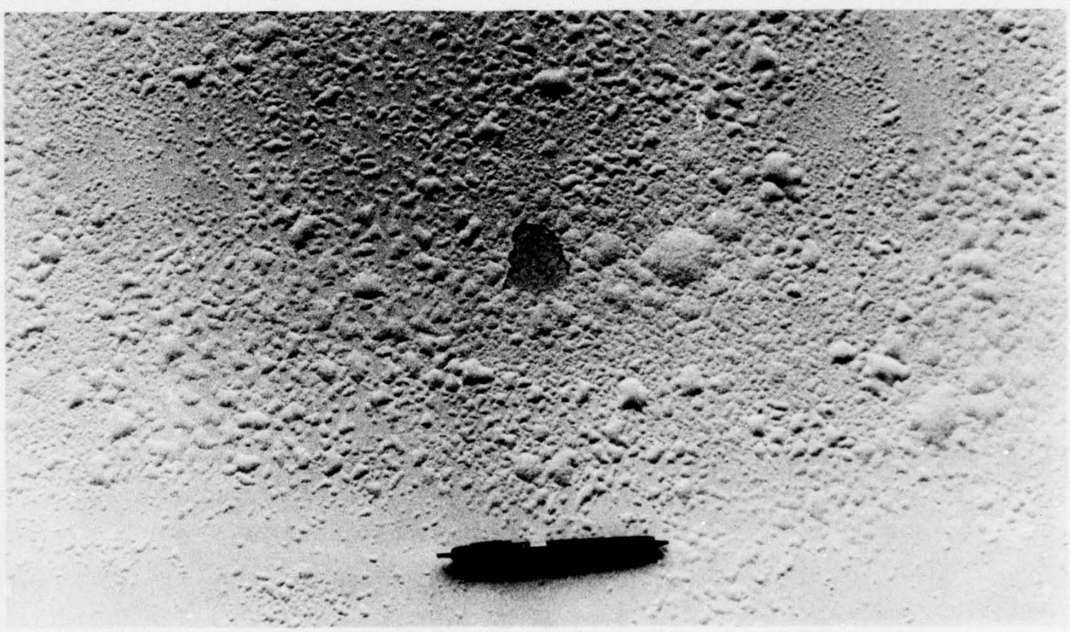
Figure 6. Location of reflective finish systems in Hangar 122.

Figure 7. Applicator wearing golf shoes broadcasts grit into first wet finish coat using a grass seeder.

Figure 8. Application of System A with lamb's wool applicators.



(a) Overview of CRU finish showing blistering.



(b) Closeup of CRU finish showing size and frequency of blistering.

Figure 9. CRU primer and first finish coat blistered badly due to high temperature and humidity.

Figure 10. Removal of the CRU using a K-4 scarifying machine.

Figure 11. Cleaned deck ready for reapplication of CRU, System C.

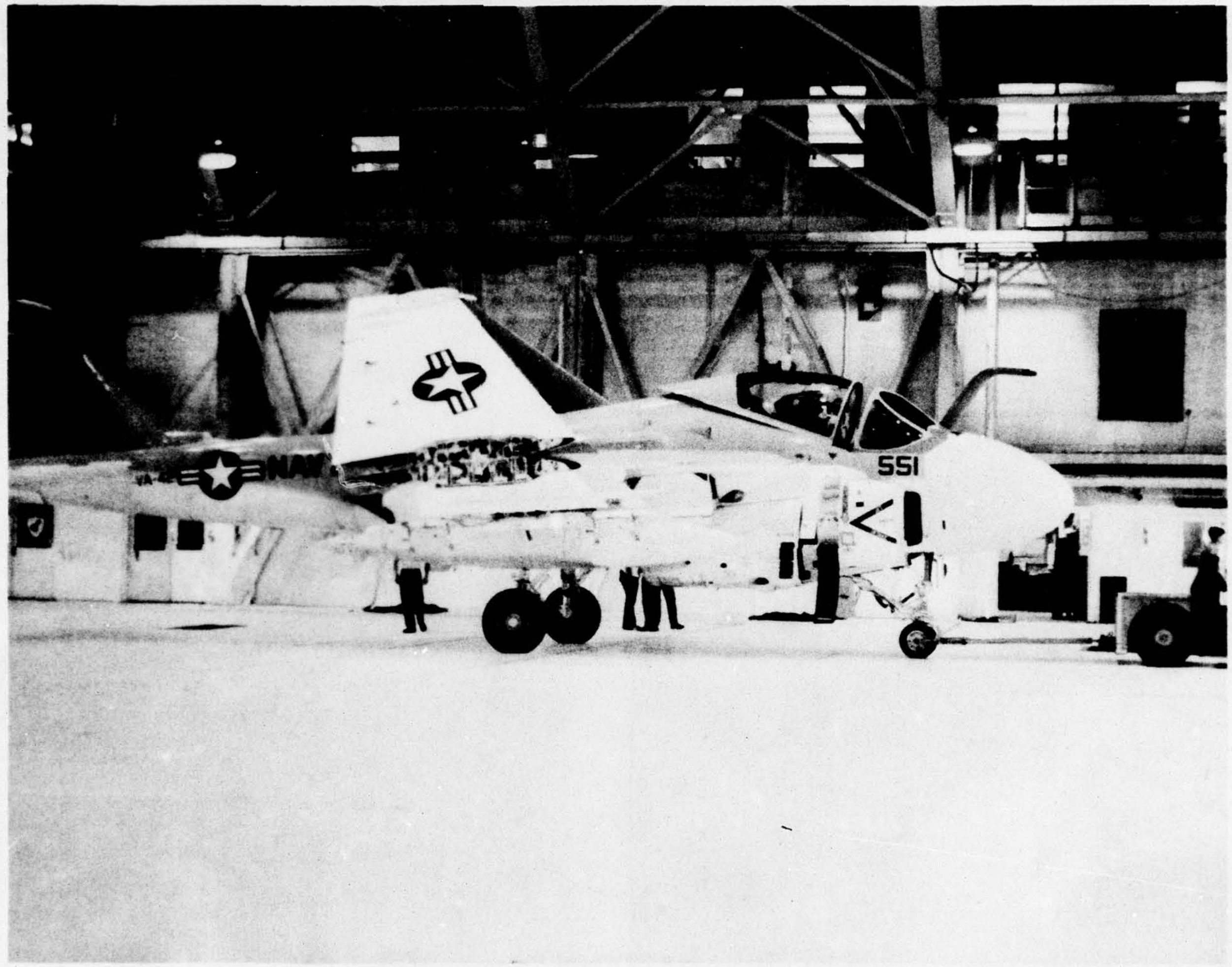
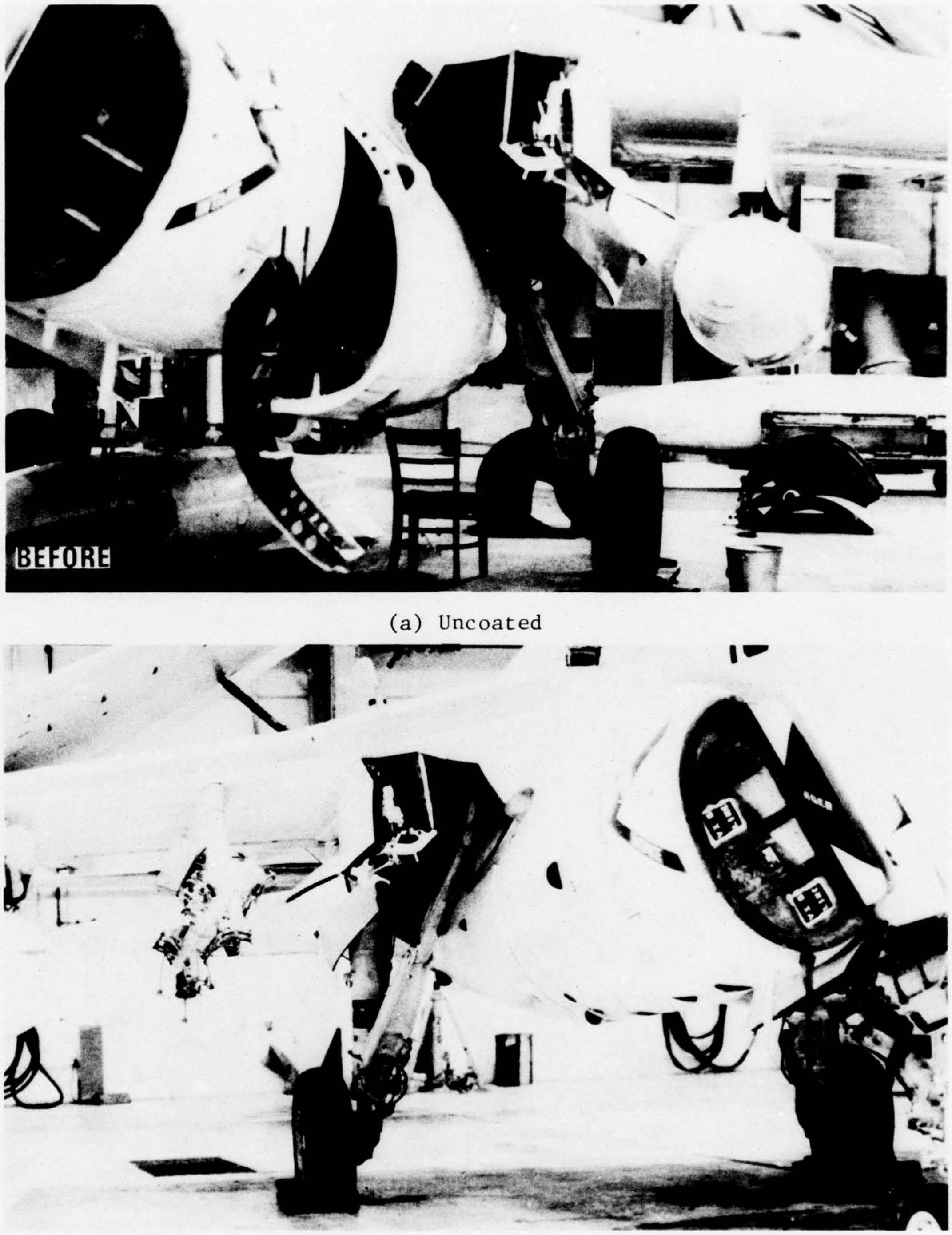


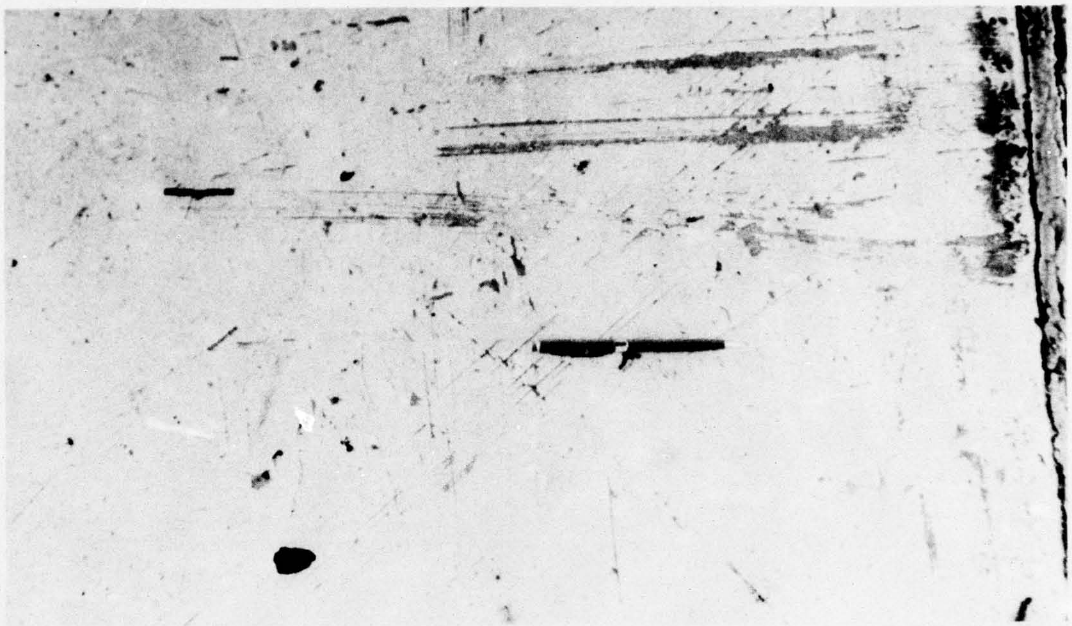
Figure 12. Reflective finish coated hangar completed except for line markings.



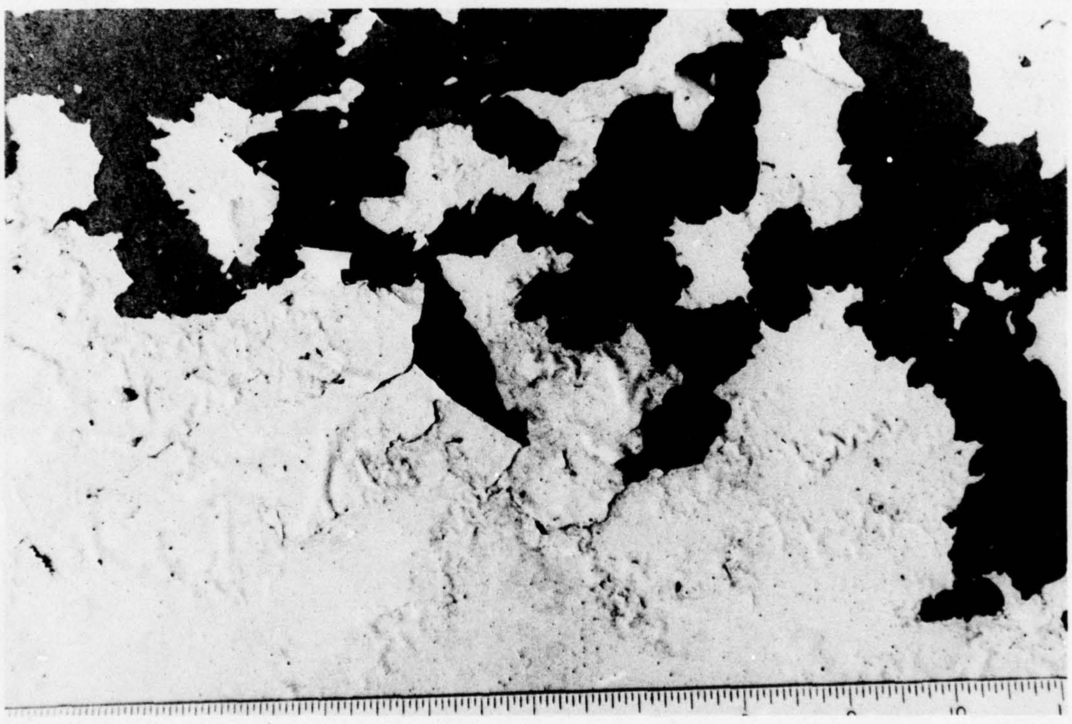
(a) Uncoated

(b) Coated

Figure 13. Comparison of underaircraft illumination on uncoated and coated hangar decks.



(a) Scratching and scraping by heavy equipment.



(b) Loss of bonding from chemical spills.

Figure 14. Damage to reflective floor finishes.

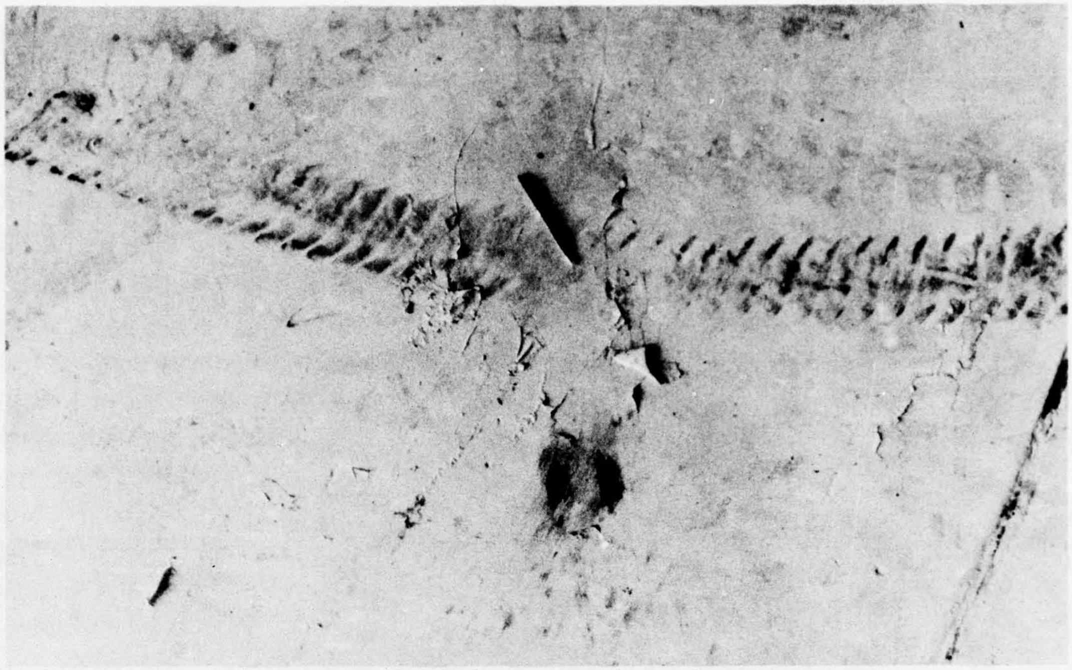


Figure 15. In a few small spots, new coating in System A area delaminated from original system.

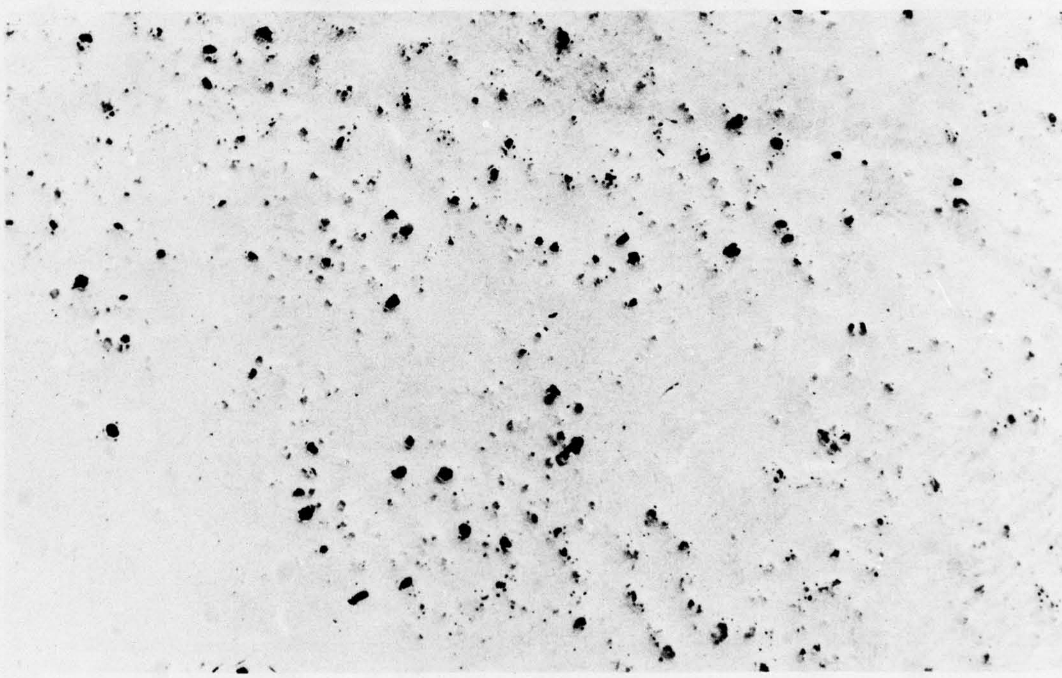


Figure 16. Photomacrograph of urethane reflective coatings after two years. Black holes in coating are where grit has been removed.

Table 1. Description of Reflective Urethane Floor Finishes

System Designation	Description	Area (sq ft)	Number of Coats	Coverage (sq ft/gal)	Total System Thickness (in. mils)	Remarks
A	TT-C-542, moisture-curing urethane – white	5,800			2.5 to 3	
	Silane sealer		1	386		clear penetrating concrete sealer-primer
	Moisture-curing urethane finish coat		1	290		first finish coat thinned 1 to 1
	Non-skid grit		1	1 lb/1,000 ft^2		grit for non-skid texture sprinkled into first wet finish coat
	Moisture-curing urethane finish coat		1	232		
B	Moisture-curing urethane – white	27,400			3.5 to 4	
	Catalyzed epoxy primer		1	586		clear epoxy primer pigmented with 1/2 pint per gallon of white color coat
	Moisture-curing urethane finish coat		1	179		clear urethane finish coat pigmented with 2 pints per gallon of white color coat
	Non-skid grit		1	1 lb/1,000 ft^2		grit for non-skid texture sprinkled into first wet finish coat
	Moisture-curing urethane finish coat		1	179		clear urethane finish coat pigmented with 1 pint per gallon of white color coat
C	Catalyzed Chemically Resistant Urethane (CRU)	5,800			4 to 5	
	Catalyzed urethane primer		1	386		
	Catalyzed CRU finish coat		1	322		
	Non-skid grit		1	1 lb/1,000 ft^2		grit for non-skid texture sprinkled into first wet finish coat
	Catalyzed CRU finish coat		1	414		

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Table 2. Incident and Reflected Illumination During Daylight Before and After Co

Age of Coating in months (type of sunlight)	Type of Illumination	Areas						
		Total			System A			
		Lamps out (%)	Illumination (FC/L)[a]	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)	Reflected[b] (%)	Lamps out (%)
a. Grid Points Within Areas								
Uncoated control-1[c] (hazy sun)	Incident Reflected	24	82 36	44	25	86 30	35	21
0.5 month (bright sun)	Incident Reflected	43	106 85	80	42	126 97	77	42
6 months (overcast)	Incident Reflected	26	88 52	59	0	106 65	61	31
b. Grid Points Underneath Aircraft								
Uncoated control-1[c] (hazy sun)	Incident Reflected	24	50 20	40	25	52 12	23	21
0.5 month (bright sun)	Incident Reflected	43	77 72	94	42	93 113	122	42
6 months (overcast)	Incident Reflected	26	67 34	51	0	–[d] –	–[d]	31

[a]In foot-candles per lamp.
[b]Percent reflected is percent of incident illumination reflected.
[c]Uncoated control – test hangar before coating.
[d]No aircraft in this area.

n During Daylight Before and After Coating Hangar Decks

Areas							
System A		System B			System C		
llumination (FC/L)	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)	Reflected[b] (%)
d Points Within Areas							
86 30	35	21	80 37	46	33	89 34	38
126 97	77	42	85 67	79	50	170 144	85
106 65	61	31	89 52	58	33	65 40	62
oints Underneath Aircraft							
52 12	23	21	43 23	53	33	65 19	29
93 113	122	42	56 54	96	50	138 108	78
–[d] –	–[d]	31	83 36	43	33	22 29	132

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Table 3. Average Incident and Reflected Illumination After Dark Before and After Coating Hangar Decks

Age of Coating (in months)	Type of Illumination	Areas											
		Total Hangar			System A			System B			System C		
		Lamps out (%)	Illumination (FC/L)[a]	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)[a]	Reflected (%)	Lamps out (%)	Illumination (FC/L)[a]	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)[a]	Reflected (%)
Uncoated control C-1[c]	Incident Reflected	33	17.9 1.4	8	33	16.8 1.2	7	33	18.6 1.8	10	33	14.2 1.0	7
0.5 month	Incident Reflected	44	16.8 12.1	72	42	16.3 12.5	77	42	17.9 12.2	68	58	13.0 10.7	82
6 months	Incident Reflected	25	22.3 12.0	54	0	33.5 19.5	58	29	22.2 11.3	51	33	11.4 7.3	64
9 months	Incident Reflected	21	18.4 10.3	56	0	20.3 14.0	69	27	19.4 10.0	52	17	12.0 7.5	62
15 months	Incident Reflected	30	19.5 8.0	41	0	33.0 13.5	41	33	19.2 7.6	40	50	7.0 4.0	57
24 months[d]	Incident Reflected	37	14.8 7.1	48	0	25.5 12.1	48	38	14.2 6.6	46	58	6.8 3.8	56
24 months[e]	Incident Reflected	33	15.6 7.8	50	0	25.8 12.9	50	35	15.1 7.5	50	58	7.2 3.8	53
36 months	Incident Reflected	57	7.5 3.9	52	42	10.2 5.6	55	58	7.5 3.8	51	67	5.1 2.6	51
Uncoated control C-2[c]	Incident Reflected	18	17.2 2.1	12	17	16.7 2.1	13	21	15.5 2.0	13	8	24.8 2.8	11

[a] In foot-candles per lamp.
[b] Percent reflected is the percent of incident light reflected.
[c] Uncoated control C-1 – test hangar before coating; uncoated control C-2 – west barrel of hangar C-2 at 6-month inspection.
[d] Readings taken before cleaning hangar deck.
[e] Readings in Area A and half of Area B taken after cleaning.

Table 4. Average Incident and Reflected Illumination Underneath Aircraft, After Dark, Before and After Coating Hangar Decks

Age of Coating	Type of Illumination	Area											
		Total Hangar			System A			System B			System C		
		Lamps out (%)	Illumination (FC/L)[a]	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)[a]	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)[a]	Reflected[b] (%)	Lamps out (%)	Illumination (FC/L)[a]	Reflected (%)
Uncoated control C-1[c]	Incident[d] Reflected	33	7.4 0.2	1	33	9.0 0	0	33	7.6 0.4	2	33	5.7 0	0
0.5 month	Incident Reflected	44	3.6 6.8	40	42	2.5 6.5	40	42	4.0 6.6	37	58	4.0 8.0	62
6 months	Incident Reflected	25	4.5 6.4	29	0	3.0 10.0	30	29	6.0 7.0	32	33	2.2 3.6	32
9 months	Incident Reflected	21	2.4 6.3	34	0	2.7 9.3	46	27	2.8 5.0	26	17	1.6 4.8	40
15 months	Incident Reflected	30	3.4 3.6	18	0	8.0 4.0[e]	12	33	2.5 4.5	23	50	3.2 2.8	40
24 months[f]	Incident Reflected	37	3.3 3.6	24	0	3.0 6.0[e]	24	38	3.4 3.7	26	58	2.0 2.3	34
24 months[g]	Incident Reflected	33	3.7 3.4	21	0	0 1.0[e]	4	35	4.6 4.3	28	58	3.0 2.3	32
36 months	Incident Reflected	57	0.9 2.0	27	42	1.0 0[e]	0	58	1.3 2.4	32	67	0 1.0	20
Uncoated control C-2[c]	Incident Reflected	18	4.4 1.4	8	17	3.3 1.3	8	21	3.7 1.2	8	8	8.7 2.3	9

[a] In foot-candles per lamp.
[b] The percent illumination reflected underneath the aircraft was calculated by dividing the reflected illumination given in this table by the incident illumination for the same time period/hangar area from Table 3.
[c] Uncoated control C-1 – test hangar before coating; uncoated control C-2 – west barrel of Hangar 122.
[d] Incident illumination underneath aircraft often represented light reflected from underneath side of aircraft.
[e] Based on only one underaircraft reading.
[f] Readings taken before cleaning hangar deck.
[g] Readings in Area A and half of Area B taken after cleaning.

Table 5. Comparison of Average Incident and Reflected Illumination, After Dark, in South Half of Hangar Deck Before and After Cleaning
[coating age is 24 months.]

Cleaning	Type of Illumination	Total Hangar			System A Area			System B Area[a]		
		Lamps out (%)	Illumination (FC/L)[b]	Reflected[c] (%)	Lamps out (%)	Illumination (FC/L)[b]	Reflected[c] (%)	Lamps out (%)	Illumination (FC/L)[b]	Reflected[c] (%)
Before	Incident Reflected	12	19.4 9.1	47	0	25.5 12.1	48	20	15.8 7.4	47
After	Incident Reflected	12	20.3 10.5	52	0	25.8 12.9	50	20	17.0 9.1	54

[a] Only 45% of System B area was cleaned and is included here; System C area was not cleaned and is thus not included.
[b] In foot-candles per lamp.
[c] Percent reflected is the percent of incident light reflected.

Table 6. Performance of Reflective Floor Finishes

Designation	Performance Rating[a] After the Following Months of Exposure—					Remarks
	0.5	9	15	24	36	
System A (TT-C-542, moisture-curing urethane)	excellent	excellent	very good	good–very good	good	Western half of area contained no grit; recoated with grit after 12 months. Major deterioration due to scraping and chemical spills. Color yellows.
System B (moisture-curing urethane)	excellent	very good	very good	good	good	Southwest corner rated fair–good after 8 months and recoated. Loss of bonding between primer and first topcoat was major problem. Major deterioration due to scraping and chemical spills. Color yellows.
System C (CRU)	excellent	excellent	excellent	excellent	very-good–excellent	Excellent performance. Where coating removed by scraping, concrete deck gouged. Color retains whiteness.

[a] Performance ratings:
Excellent – little or no coating deterioration.
Very good – a minimal loss of coating.
Good – less than 5 percent of coating removed.
Fair – 5 to 10 percent of coating removed.

[b] 95 percent of grit scraped from deck coating within 1 to 2 years after application.

Appendix A

TEST PLAN FOR THE STUDY OF REFLECTIVE FINISHES FOR IMPROVED ILLUMINATION OF AIRCRAFT MAINTENANCE HANGARS AT NAS OCEANA, VIRGINIA

ACTION	BY
OBJECTIVE: To determine the feasibility, both economical and operational, of improving illumination at the underside of air craft in Navy maintenance hangars using a reflective floor coating.	
APPROACH: Following approval of this test plan, the objectives of this RDT&E effort will be met in the following manner:	
1. The contractual document specifying the reflective coating system(s) to be used, the surface preparation and application procedure will be prepared and awarded.	PWO Oceana and LANTDIV reviewed by CEL
2. Prior to application of the test reflective coating system, the following information and data will be obtained:	
a. A survey will be conducted in the hangar to be included in the test to determine the extent to which dropcords, flashlights and other mobile lighting are used in maintenance operations.	PWO Oceana, LANTDIV and Navy Safety Center
b. A survey of both the direct and reflective lighting levels of the existing system will be conducted in the test hangar. An unmarked three-dimensional grid will be established in relation to the hangar's lighting arrangement so that the initial and subsequent illumination readings can be	PWO Oceana, LANTDIV and CEL

	b. continued made at the same points. Readings will be taken both in hours of sunlight and of darkness. The readings of primary interest will be those taken underneath the aircraft during the hours of darkness when illumination is by artificial light.	
	c. Human Engineering factors will be investigated. This will involve determining personnel attitudes toward the existing environment (uncoated floor) with respect to the effect the environment has on personnel carrying out their duties of maintaining aircraft, and normal deck maintenance and cleanup procedures.	Navy Safety Center and LANTDIV
	d. Insofar as possible, the time required for aircraft maintenance, and normal deck maintenance and cleanup procedures will be determined.	PWO Oceana and LANTDIV
	e. The effect of the environment on safety factors will be investigated.	Navy Safety Center, LANTDIV and CEL
3.	Routine deck coating maintenance and cleanup procedures will be scheduled in cooperation with the squadrons located in the test hangar.	PWO Oceana, LANTDIV and CEL
4.	The reflective coating system(s) will be applied.	Contractor monitored by LANTDIV and CEL
5.	After the squadron has resumed normal hangar operations, 2a, b, c, d and e will be repeated on a periodic basis.	See under items 2a through 2e.

6.	When sufficient data has been collected, a report of findings will be prepared.	CEL and LANTDIV

Appendix B

CONTRACT SPECIFICATION FOR APPLICATION OF REFLECTIVE FINISHES TO FLOOR OF EAST BAY, HANGAR 122, NAS OCEANA
NAVFAC SPECIFICATION NUMBER 05-72-0446

TECHNICAL PROVISIONS - SECTION 2
GENERAL REQUIREMENTS

2.1 SCOPE: This section covers the general requirements and coordination of performance of this contract.

2.2 SITE VISITATION: The bidder is expected to visit the site and acquaint himself with the facilities, limitations, scope of the project, and conditions of the floors to be treated.

2.3 FACILITY UTILIZATION: The hangar, which was constructed in 1956, is presently occupied by Naval Air Squadrons VA-42 and VA-178 for maintenance operations for aircrafts.

2.4 PREVIOUS TREATMENT: The original construction documents called for the concrete floor to receive an application of chemical concrete floor hardener of zinc and/or magnesium fluosilicate. An area 29 feet by 65 feet has been coated with a combination of Standard Federal Specification white traffic paint and Tennant 420 Urethane. There may have been other types of application made to the floor but there is no record of them. Present maintenance procedures consist of the use of absorbents for spilled fuels and oils with general sweeping as required.

2.5 COORDINATION OF OPERATIONS: All of the required coordination during the execution of this contract will be with the Officer in Charge of Construction (OICC) or his authorized representative. Minimum disruption of operations is a requirement during the work being done under this contract. It is the intent that all work will start in a certain area and be completed in an expeditious manner before moving to another area. After the start of work in any area, the time allowed until the work is completed and the area is ready for resumption of normal traffic is not to exceed four calendar days. Any equipment or material temporarily stored in the area will be moved by government personnel and equipment upon reasonable notice of at least 5 days of intent to work in the area. Only one-half of the total work area will be made available to the Contractor at any one time. This will have to be scheduled so as to not disrupt the occupants any more than absolutely necessary.

2.6 WARRANTY: All floor coatings provided hereunder, shall be warranted by the Contractor in the same manner required by Clause 31 ''Warranty'', of Form NAVFAC 4-4330/5 for mechanical and electrical equipment.

2.7 VENTILATION: Proper ventilation of the work area shall be maintained at all times to prevent the accumulation of hazardous fumes.

TECHNICAL PROVISIONS - SECTION 3

FLOOR TREATMENT

3.1 SCOPE: This section covers patching, cleaning, and coating of the concrete floor in the east bay of the hangar. The total floor area to be treated is approximately 39,261 square feet. This total area is to be divided into parts that are to be coated with these (3) different systems as indicated under Section 5 of these specifications. The following work shall be included:

a. The entire east bay floor within the work area shall be patched to have all defects restored to a smooth level surface.

b. The entire work area of the east bay floor shall be cleaned to remove all dirt, grease, oil, fuel, paint, etc.

c. Part ''A'' shall receive two coats of polyurethane conforming to Federal Specification TT-C-542b, dated 23 September 1970, Type II, color shall be white.

d. Part ''B'' shall receive two coats of Tennant 420 Urethane. Prior to receiving the urethane, the surface shall receive one coat of the manufacturer's recommended primer. Final two coatings shall be white.

e. Part ''C'' shall receive two coats of Tennant 474 chemical resistant coating. Prior to receiving chemical resistant coatings, the surface shall receive one coat of the manufacturer's recommended primer. Final two coatings shall be white.

f. Floor Markings: All areas shall be provided with floor markings of same size and color as existing. The floor markings shall be provided by using an additional coat of the same type coating as the top coat of the particular coating system, except that it shall be of the color necessary.

3.2 MATERIALS AND METHODS: For Part ''A'' all materials and methods of application shall be in strict accordance with the provision of Federal Specification TT-C-542b and the recommendation of the manufacturer. Certification by the manufacturer to the above will be required, together with a copy of the test data showing conformance, before the work is started. In addition, two quart samples of the same batch of TT-C-542b that is to be applied to Part ''A'' shall be deposited with the OICC at least four weeks before application. For Parts ''B'' and ''C'', materials and methods of application shall be in strict accordance with the recommendations of the manufacturer of the products used. Complete product data on all products to be used shall be presented to the OICC.

3.3 PATCHING FLOOR: Urethane or epoxy base resin filling materials shall be used. All cracks 1/4 inch wide or wider shall be cleaned, chipped, and properly prepared for the application of the filling materials. After application, the material will be compressed to level as recommended by the manufacturer.

3.4 FLOOR CLEANING: All materials are to be standard products of Tennant and shall be prepared in the dilution and applied at the square foot coverage rate recommended by the manufacturer.

a. Remove old paint, seals, hardeners with a nonflammable type paint remover or by mechanical means where the thickness of the paint or seal dictates.

b. Floors shall be scrubbed with a detergent (Tennant's 601 Degreasing) of not less than 70% active ingredients of which 22% may be phosphates. The detergent shall be of a low residue or no-residue type. The floors shall be scrubbed clean.

c. The floor shall be rinsed with clean water and shall be mopped or vacuumed of the residue.

d. Steps a, b, and c shall be repeated until the floors are clean and approved by the OICC.

e. After the floor is cleaned and approved as in step d, a precoat cleaner (Tennant's 410) shall be applied. It shall be diluted one volume of concentrate to no more than four volumes of clear water. No muriatic or hydrochloric acid compounds shall be used. The precoat cleaner solution shall be applied to the floor at the rate of 100 square feet per gallon in accordance with manufacturer's instructions.

f. The floor shall be scrubbed with a detergent as in Section b and then rinsed with clear water. The scrubbing and rinsing shall be repeated until no residue remains. The floors will then be mopped or vacuumed of all rinse water.

g. The floors shall be allowed to completely dry and be kept free of all traffic, until coatings have been applied and properly cured.

3.5 FLOOR PRIMER: (Parts ''B'' and ''C'' only). When floors are completely dry an epoxy primer shall be applied to the floors at the manufacturer's recommended rate and not less than 400 square feet per gallon. The primer shall be so designed as to be completely compatible with the finish coats. The primer shall be designed to penetrate the floor and provide a bonding surface both chemically and mechanically for the finish coats. Dilution with solvents of the primer will not be acceptable. Dilution of the finish coats with solvents to serve as a primer is not acceptable. If a two-part type epoxy primer is used, it shall be mixed and allowed to stand 45 minutes prior to use. No two-part primer which has been mixed shall be used after it has stood for 24 hours. The floors shall be allowed to dry for a minimum of 6 hours or until completely dry.

3.6 FLOOR COATINGS: Coatings shall be applied as follows.

a. Coating for use at Part ''A'' shall have two coats of polyurethane applied in strict accordance with Federal Specification TT-C-542b and in accordance with the manufacturer's printed instructions, dated 23 September 1970, Type II, color to be white.

b. Coatings for use at Parts ''B'' and ''C'' are to be applied as follows.

(1) Apply first coat of an oil-free moisture-cure colorless urethane of not less than 45 percent solids at the rate of 350 square feet per gallon (2 mil thickness). Minimum drying time under ideal atmospheric conditions and air movement is 6 hours. Resealed cans that have been partially used shall be discarded seven days after initial opening date. During application of the coatings, the temperature must be 60°F or higher and at least 40 percent relative humidity.

(2) The second coat of urethane shall be applied when the first coat has reached the proper tackiness condition but is not completely dry. If the first coat is allowed to completely dry, machine buffing with fine steel wool or nylon abrasive buffing roll is required. Following buffing, the floor shall be swept clean with cloth mop. The second coat shall be applied at a rate of 400 to 450 square feet per gallon. The second coat shall dry a minimum of 6 hours prior to opening to traffic.

(3) Where color is required, the urethane shall not have the pigment premixed. The pigment color shall be added to the clear urethane at the manufacturer's recommended rate and procedure. The color shall be white.

3.7 NONSLIP TREATMENT: Coatings for use at all three Parts shall have an approved non-slip grit applied to the surface of the first finish coat in amounts and locations as directed by the OICC. Grit shall be applied uniformly and with controlled density.

3.8 CLEANING: The contractor shall remove all unused materials and maintain area in clean acceptable condition.

3.9 MAINTENANCE MATERIALS: The contractor upon completion and acceptance of the project shall turn over to the OICC two gallons each of Tennant's 420 and 474 urethane, both white, along with complete instructions on how to make repairs to Parts ''B'' and ''C'' floor coatings.

TECHNICAL PROVISION - SECTION 4

PAINTING

4.1 SCOPE: This section covers the painting of the entire peripheral wall and doors of the east hangar bay to the height of 6 feet 8 inches. All metal, wood, and masonry surfaces located in the described wall area shall be painted unless otherwise directed by the OICC. All surfaces are to receive two coats.

4.2 GENERAL REQUIREMENTS: Surfaces to be painted shall be thoroughly cleaned and shall be dry when paint is applied. Areas shall be broom-cleaned and dust-free before and during the application of any painting material. Painting materials shall be worked thoroughly into all joints, crevices, and open spaces. Color shall be white unless indicated or specified otherwise hereinafter. Finished surfaces shall be smooth, even and free of defects. Damaged painting shall be retouched before applying succeeding coats of paint. Paints and paint materials shall be delivered in unbroken original packages bearing the manufacturer's name and brand designation. Storage of paints and paint materials and the mixing of paints shall be restricted to the locations directed. Reduction of paints to proper brushing consistency shall be accomplished by adding fresh paint; except that when thinning is mandatory for the type of paint being used, written permission to use thinner shall be obtained from the OICC. The written permission shall include quantities and types of thinners to use. Thinners shall not be permitted upon the job site unless written permission for thinning has been given by the OICC.

4.3 MATERIALS: Paint shall conform to the requirements of Federal Specification TT-E-489F, dated December 10, 1970. Color shall be manufacturer's standard white. Certification by the manufacturer, to the above will be required, together with a copy of the test data showing conformance before the work is started. In addition, two one quart samples of the same batch of TT-E-489F that is to be applied to the walls shall be deposited with the OICC at least four weeks before application.

4.4 PREPARATION OF SURFACES: All dirt, rust, scale, splinters, loose particles, disintegrated paint, grease, oil, and other deleterious substances shall be removed from all surfaces which are to be painted or otherwise finished. Existing enamel and other glossy surfaces shall have their entire surfaces sandpapered before application of any coatings. Surfaces shall be inspected and approved after preparation and before application of any coatings.

(a) Defects in surfaces, such as scratches, nicks, cracks, gouges, spalls, alligatoring and irregularities due to partial peeling of previous paint coatings shall be repaired, smoothed, sanded, spackled or otherwise treated as necessary to render them practically invisible in

the finished work. Where impracticable to satisfactorily eliminate the defects by other means, existing paint shall be removed from the entire surfaces, the surface repaired as necessary, primed and repainted. Where peeling is general over an area, including self-contained portions of a surface, all paint in such areas shall be removed and the edges of such removal shall be sanded out to provide imperceptible transition.

(b) Wiping of surfaces. After all other cleaning operations and wire brushing and sanding are completed, all previously painted surfaces except stucco and similarly rough surfaces, shall be wiped down with clean rags saturated with mineral spirits which shall be allowed to dry. Such wiping shall immediately precede the application of the first coat of any coating, except as specified otherwise.

(c) Wood surfaces shall be free from dust and in an approved condition to receive the paint. Previously painted interior wood surfaces shall be sandpapered over their entire area, and in addition shall be scraped as necessary to remove loose paint. All nail heads shall be set and putty stopped. Where checking of the wood is present, the surface shall be sanded down smooth, wiped and a coat of pigmented orange shellac shall be applied and allowed to dry before further paint is applied. Open joints and all other openings shall be filled with white lead whiting putty and sanded smooth after it has dried.

(d) Concrete and masonry. Dirt, fungus, grease, and oil shall be removed prior to application of paint. Previously unpainted surfaces shall be washed with a solution composed of from 2 to 8 ounces of trisodium phosphate per gallon of hot water and then rinsed thoroughly. Glaze and all loose particles and scale shall be removed by wire brushing.

(e) Existing metal surfaces to be painted shall have all deleterious substances removed as specified herein before and shall be sandpapered, wire brushed or rubbed with steel wool over their entire surfaces, and scraped where necessary to remove loose paint. Any rusted spots shall be cleaned down to bare metal including spots where rust discoloration appears through the existing paint. The removal shall be to the extent that only rust discoloration in deep pits remains. Otherwise, the surfaces shall be cleaned to bright metal. Immediately after such cleaning and before any new rust has formed, the bare surfaces shall receive a coat of rust arresting compound conforming to specification MIL-R-10036; after the compound is thoroughly dry and hard, such surfaces shall receive primer coats conforming to TT-P-645.

4.5 APPLICATION OF PAINT: Metal, wood, concrete, and masonry surfaces shall receive two coats of enamel conforming to Federal Specification TT-E-489F. The finished surfaces shall be free from runs, drops, ridges, eaves, laps, brush marks, and variations in colors. Paints shall be applied carefully with clean brushes, except that areas made inaccessible to brushing by ducts and other equipment may be sprayed. Spray equipment shall be the airless types. The work shall be so conducted as to avoid contamination on other surfaces and public and private

property in the area; any damage thereto shall be made good by the Contractor at his expense. Sufficient time shall be allowed between coats to permit thorough drying, and each coat shall be in proper condition to receive the next coat. Each coat shall be sufficiently heavy to cover completely the preceding coat or surface; there shall be an easily perceptible difference in shades of successive coats of paint.

TECHNICAL PROVISIONS - SECTION 5
DRAWINGS

Figure B-1, B-2, and B-3 describe the building and the floor plan and areas for the tests.

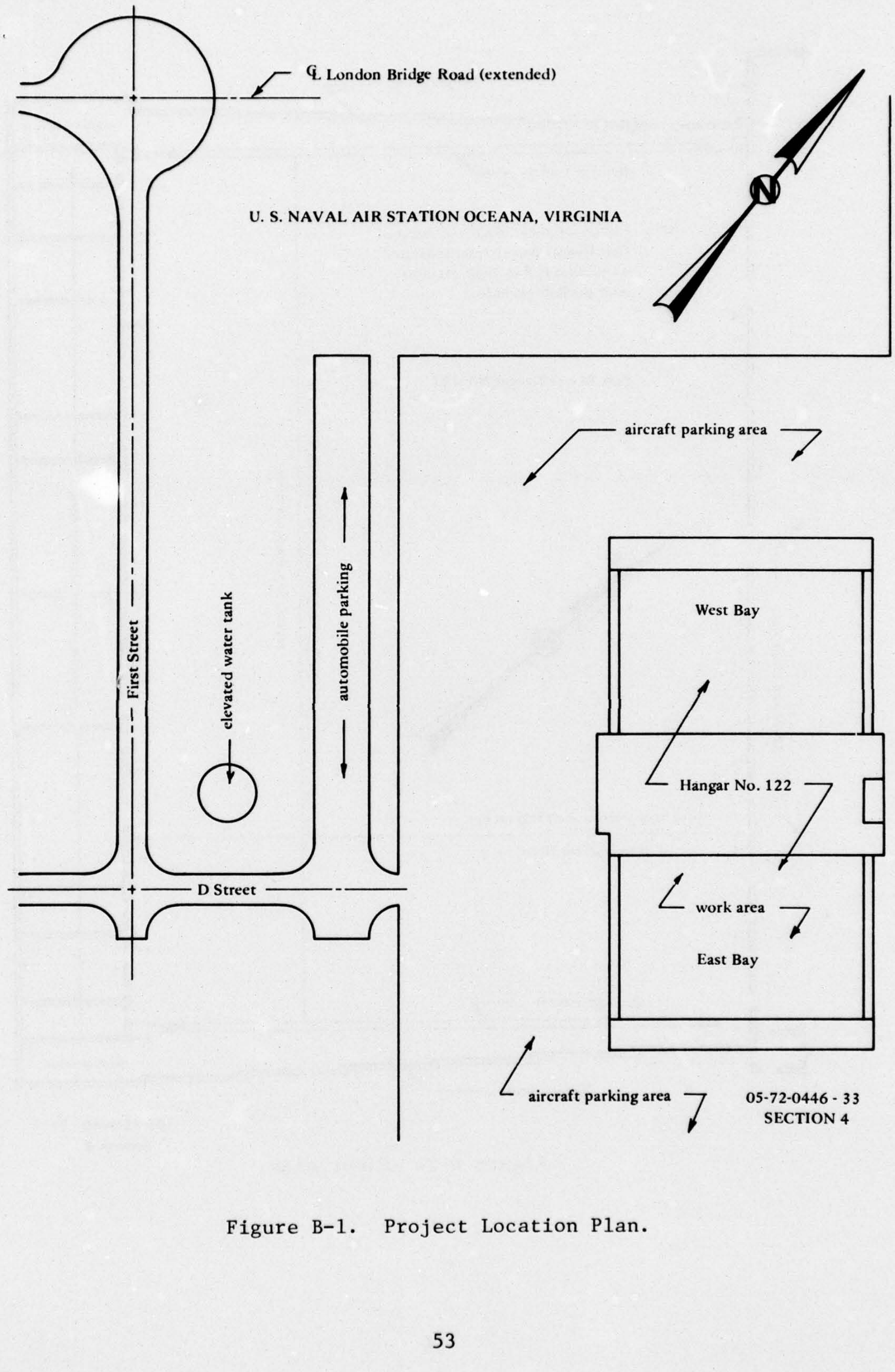

Figure B-1. Project Location Plan.

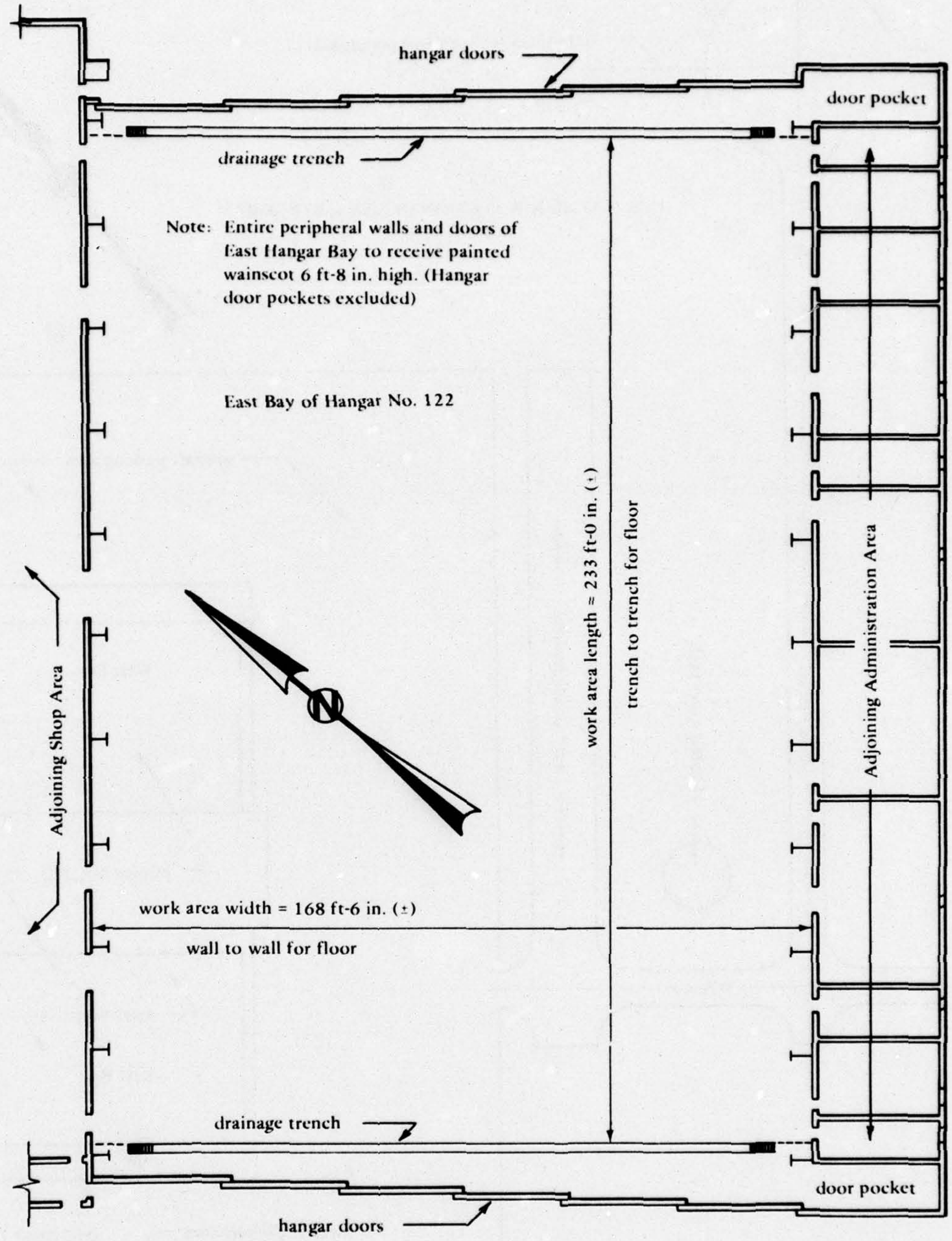

Figure B-2. Floor plan.

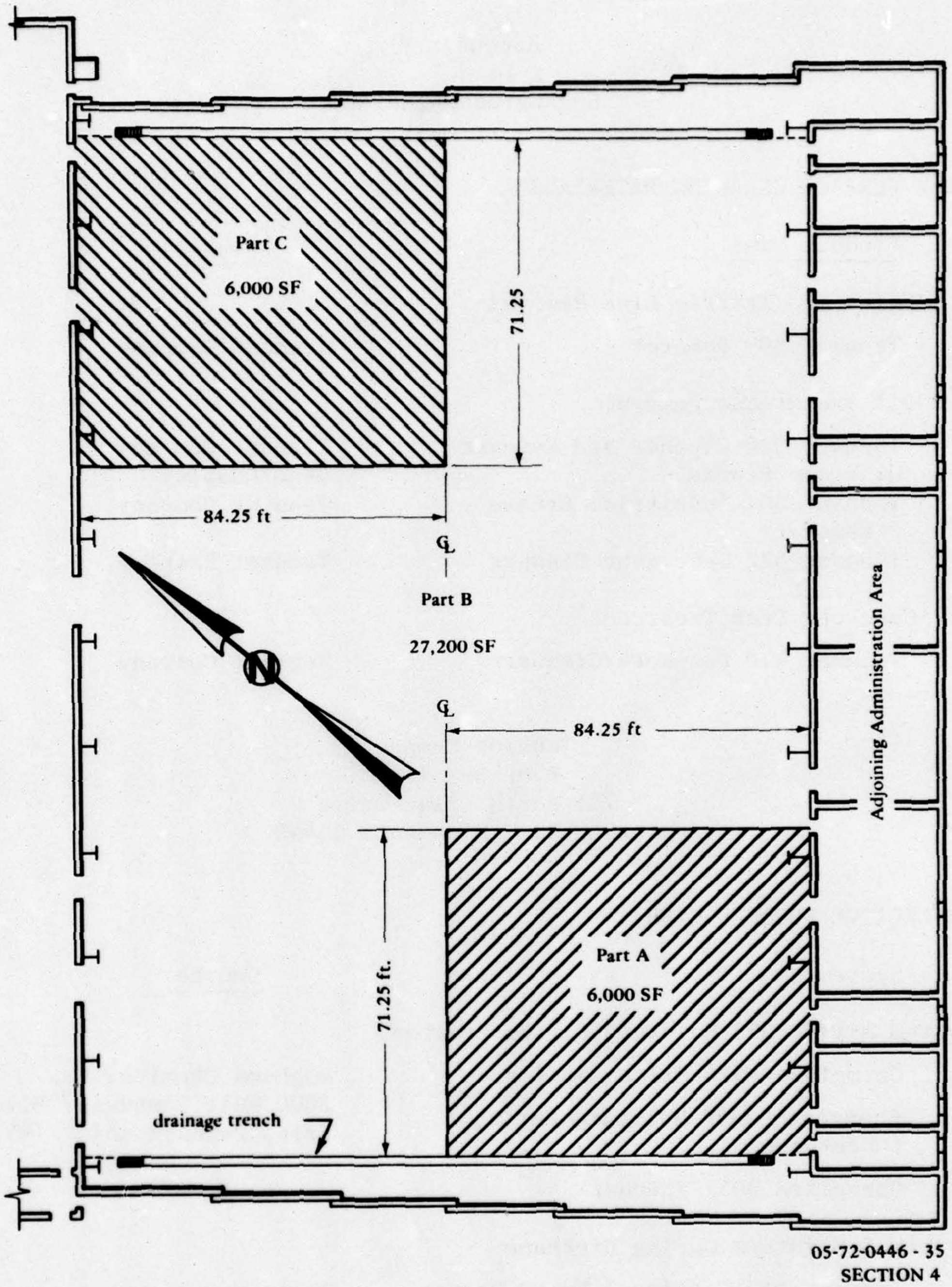

Figure B-3. Test pattern layout.

Appendix C

SOURCE OF MATERIALS

DECK SURFACE CLEANING MATERIALS

Product Name	Source
1. Paint and Traffic Line Removal	
Tennant 509 Remover	Tennant Company
2. Oil and Grease Removal	
Tennant 528 Cleaner and Remover	Tennant Company
Hi Flash Naptha	Esso Company
Tennant 601 Industrial Grease Remover	Tennant Company
Tennant 622 Detergent Cleaner	Tennant Company
3. Concrete Etch Treatment	
Tennant 410 Pre-Kote/Cleaner	Tennant Company

Tennant Company
P.O. Box 1452
701 North Lilac Drive
Minneapolis, Minnesota 55440

REFLECTIVE FLOOR FINISH

System	Source
System A-TT-C-542 Moisture-Curing Urethane	
Chemglaze 9926 Silane Sealer	Hughson Chemical Co. 2000 West Grandview Blvd. Erie, Pennsylvania 16512
Chemglaze 2252 Moisture-Curing Urethane	
Chemglaze 9951 Thinner	
System B-Moisture Curing Urethane	
Tennant 412 Catalyzed Epoxy Primer	Tennant Company
Tennant 436 White Color Coat	Tennant Company
Tennant 420 Moisture-Curing Urethane	Tennant Company

System C-Chemically Resistant Urethane

Tennant 4766 Catalyzed Urethane Primer (formerly 472 when tested)	Tennant Company
Tennant 4760 Catalyzed CRU Finish (formerly 474 when tested)	Tennant Company

All three systems employed Tennant 295 Safewalk Grit

Appendix D

INCIDENT AND REFLECTED LIGHT READINGS AT VARIOUS INTERVALS BEFORE AND AFTER COATING HANGAR DECKS

Each of the 72 dots in Figures D-1 through D-13 represents a lamp and, hence, a grid point. A circle around the dot indicates that that particular lamp was either out or missing and hence was not supplying any illumination to the hangar. The number above the dot indicates the incident light reading in foot-candles, while the number beneath each dot represents the reflected light readings in foot-candles. A line drawn above either of these readings indicates that that particular reading was taken underneath some portion of the aircraft.

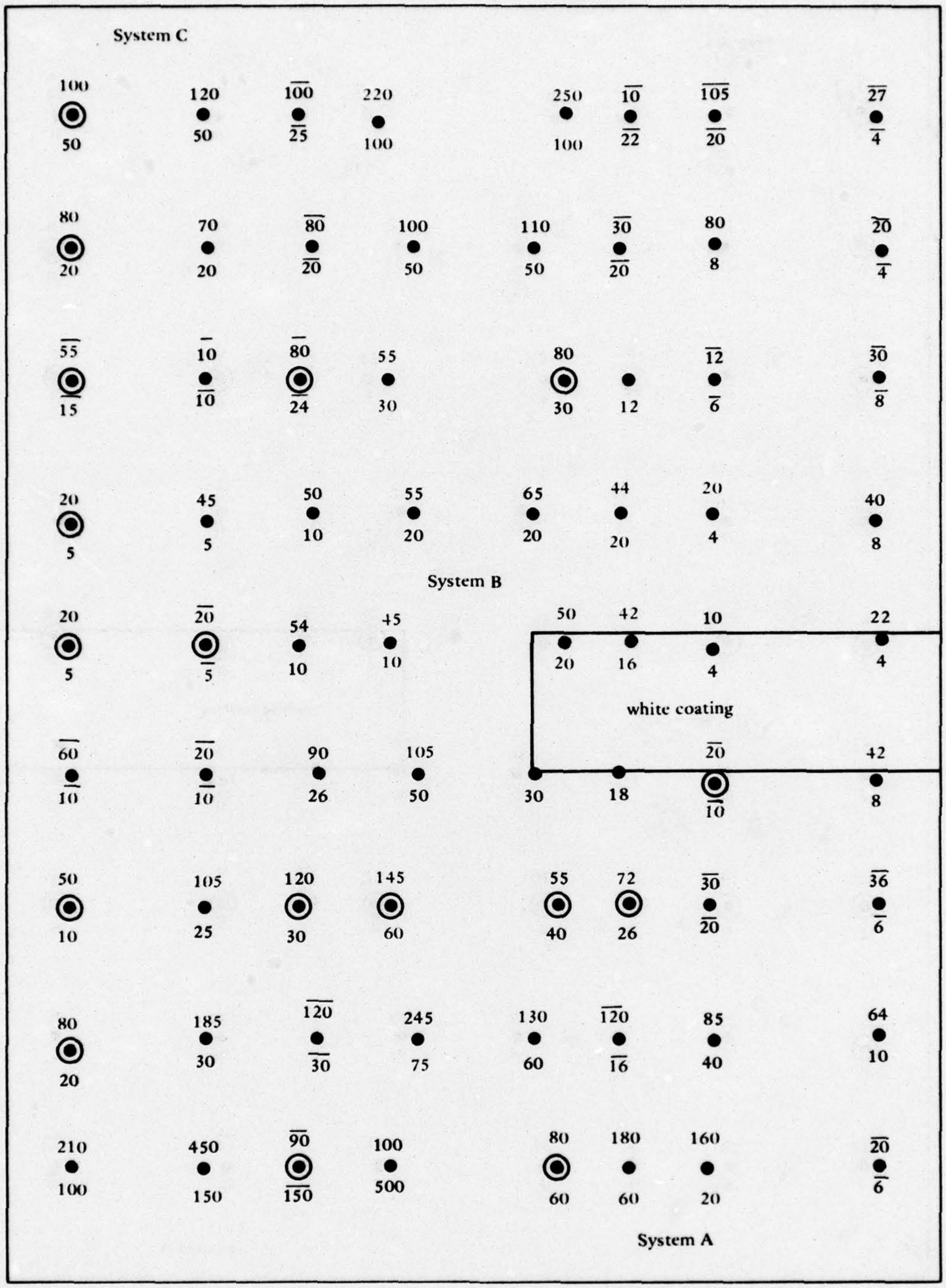

Figure D-1. Incident and reflected light readings before coating hangar deck (hazy sun, 6 July 1972).

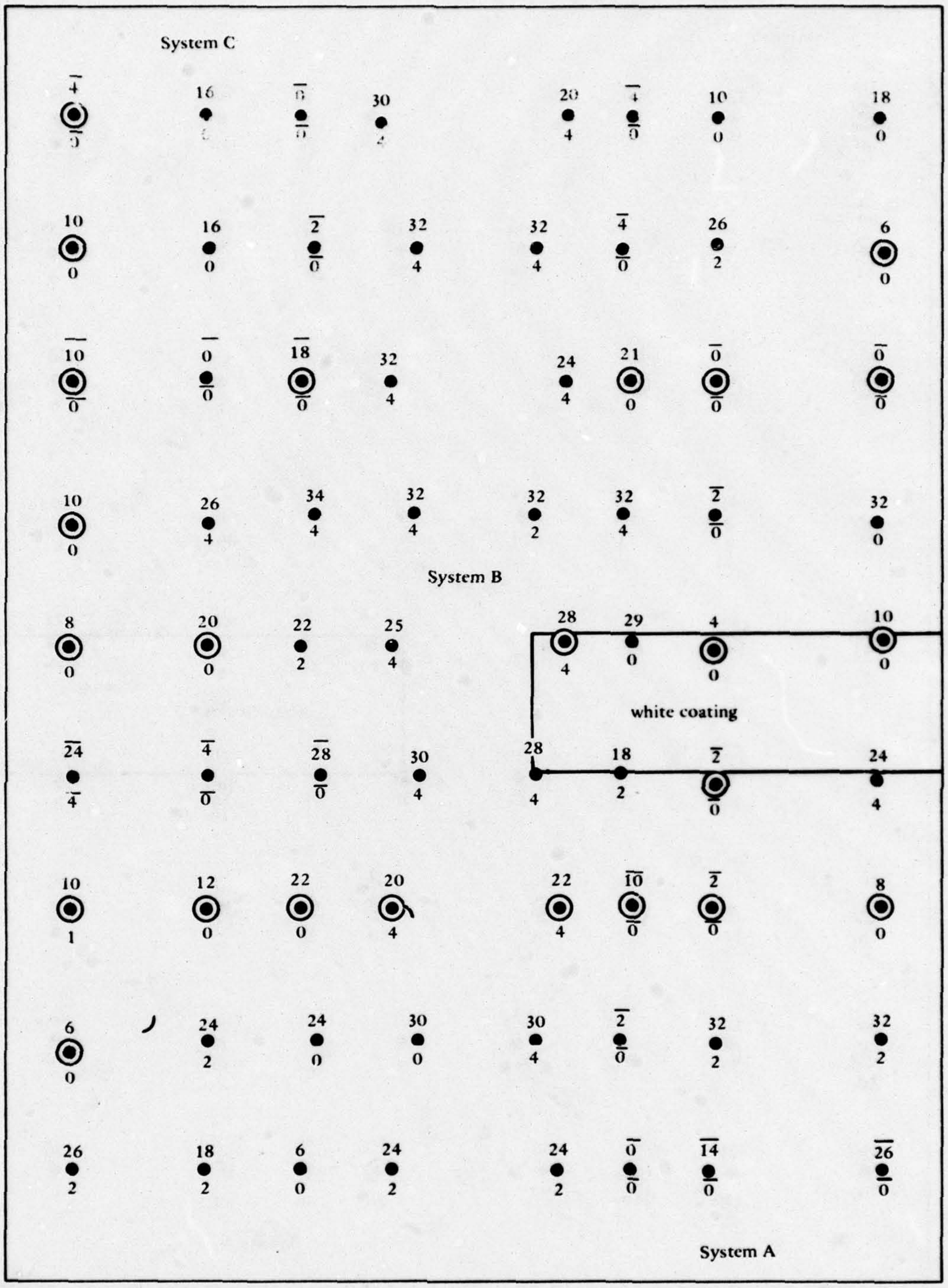

Figure D-2. Incident and reflected light readings before coating hangar deck (control-1, 6 July 1972).

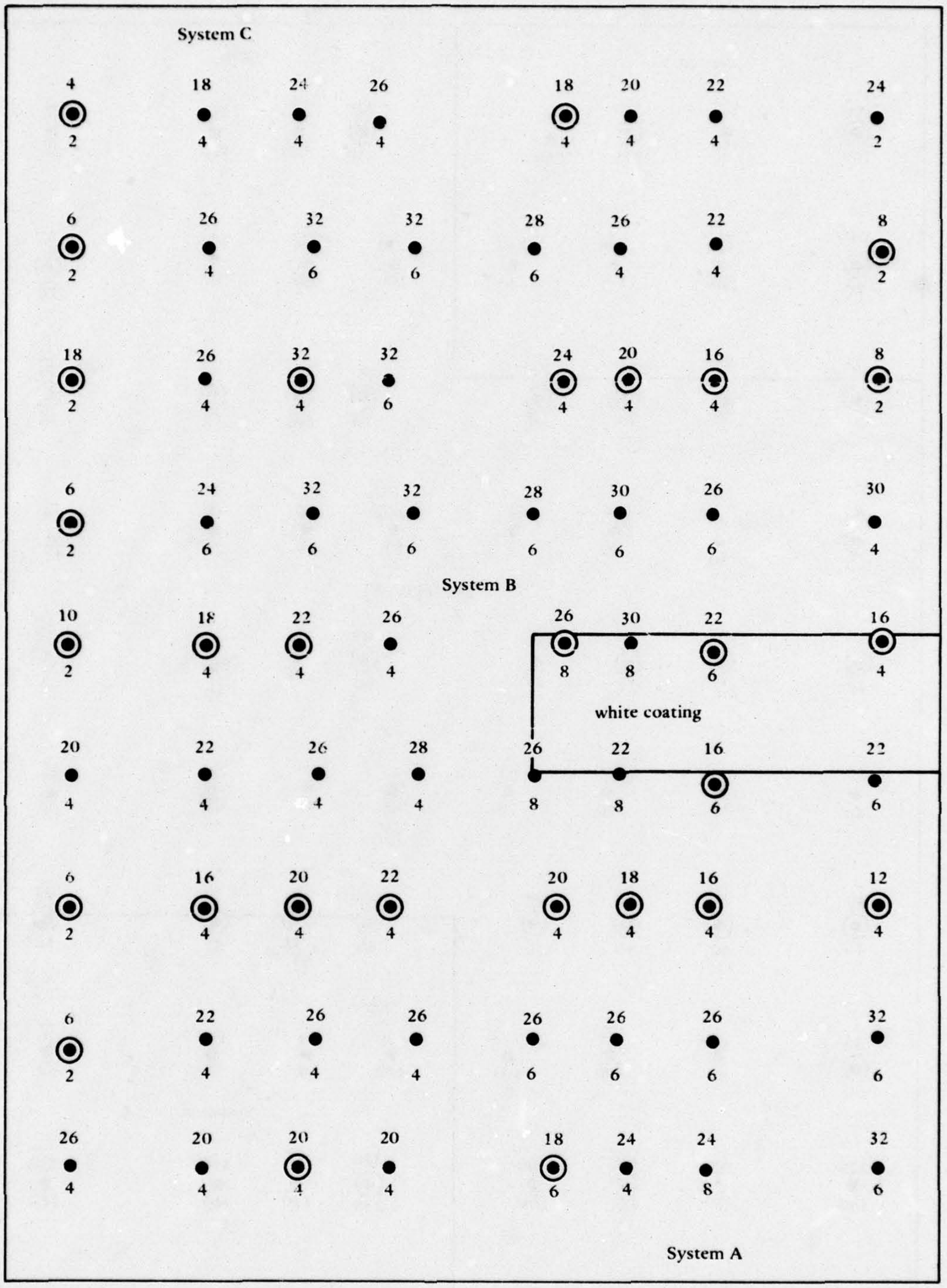

Figure D-3. Incident and reflected light readings before coating hangar decks (no aircraft in hanger, 17 July 1972).

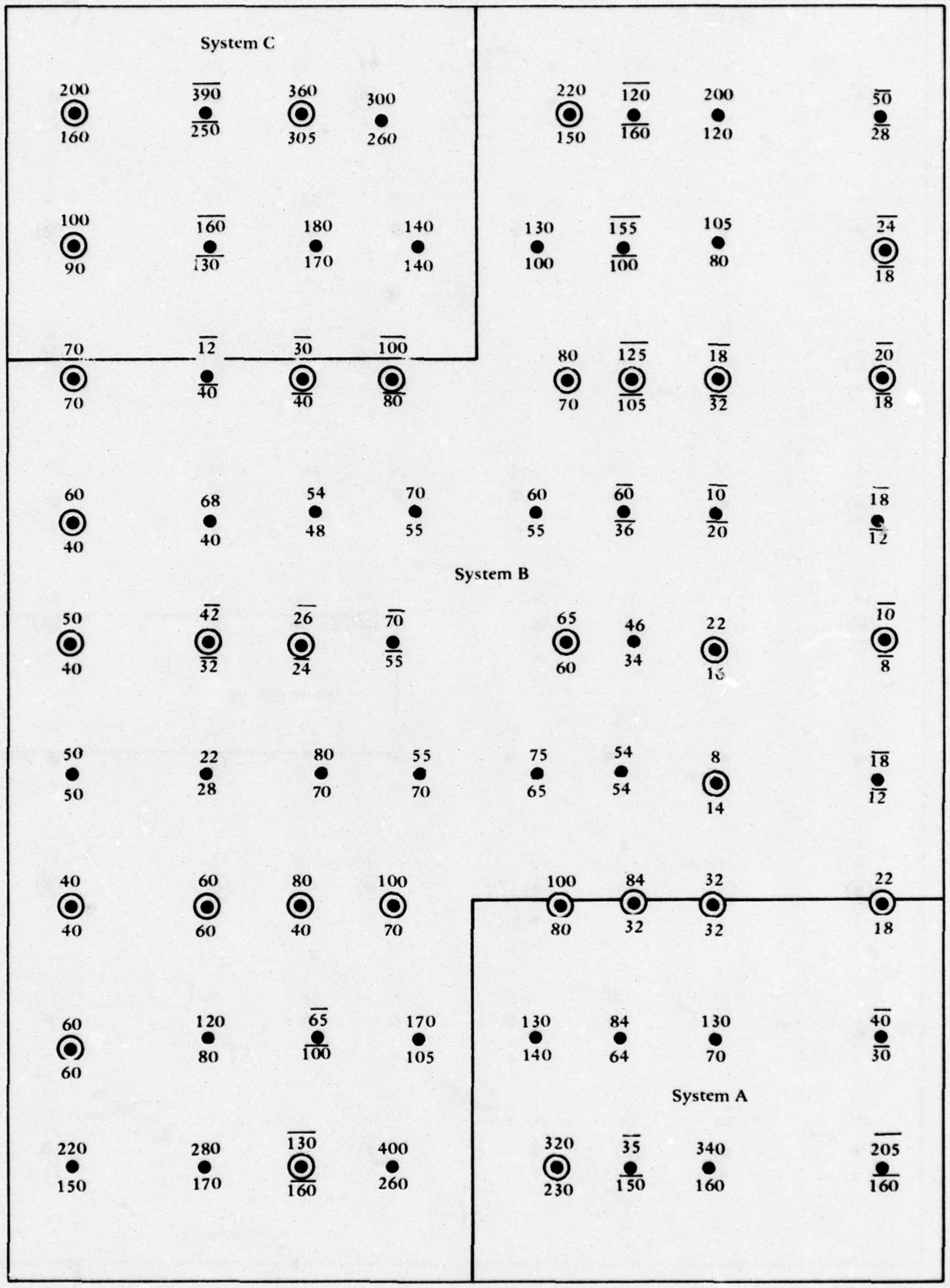

Figure D-4. Incident and reflected light readings after coating hangar deck, coating age 0.5 month (bright sun, 8 August 1972).

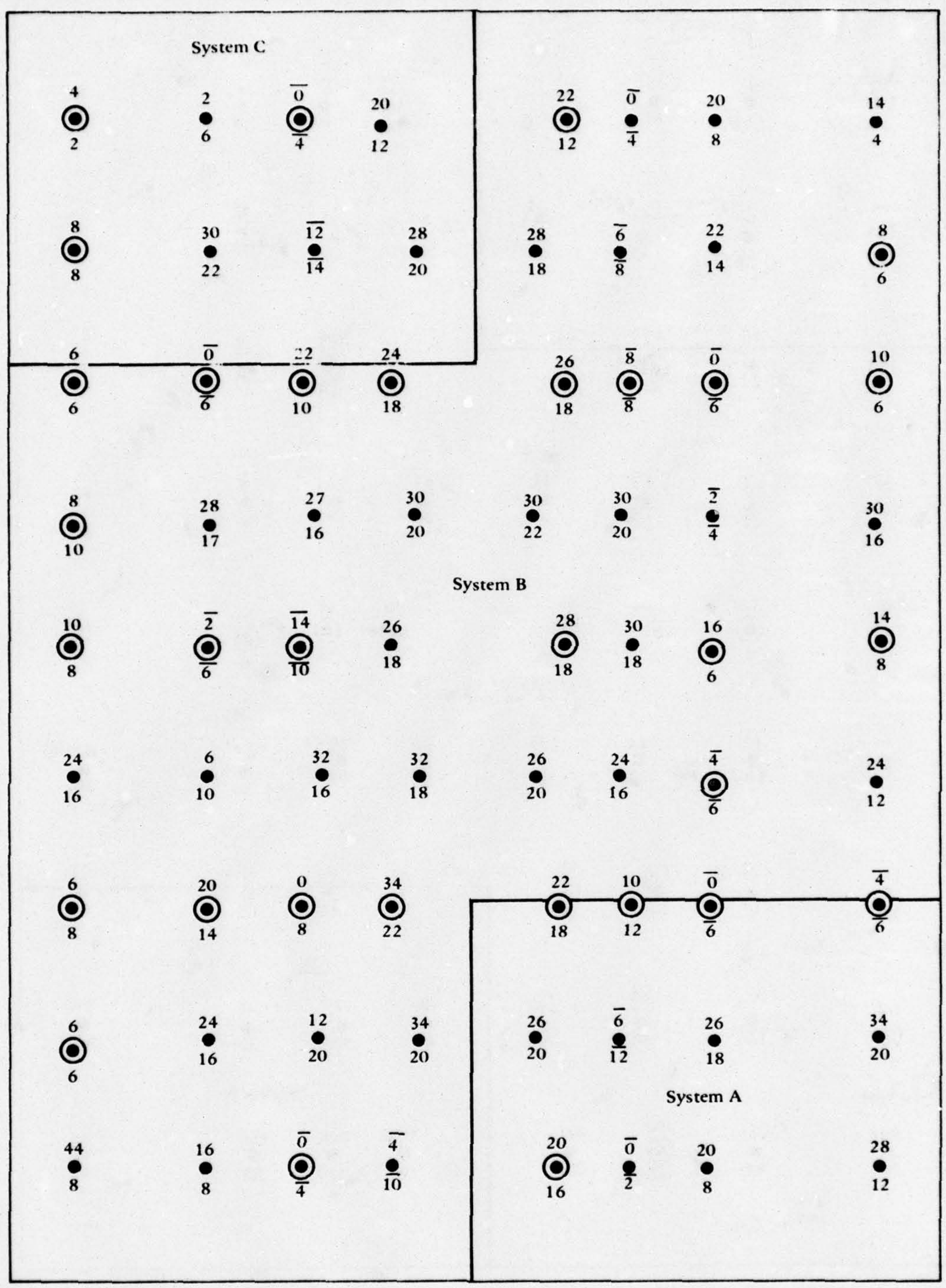

Figure D-5. Incident and reflected light readings after coating hangar deck, coating age 0.5 month (7 August 1972).

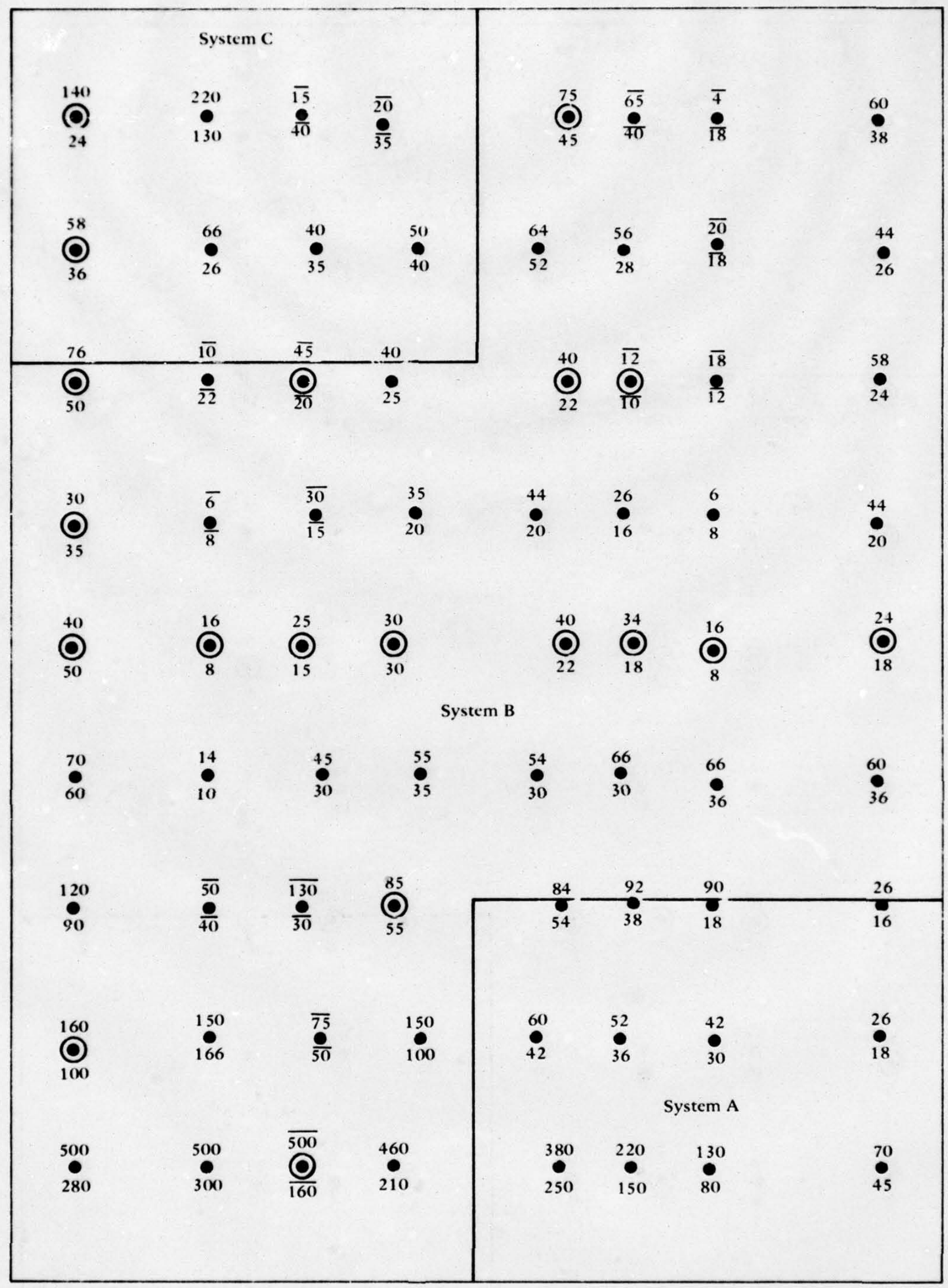

Figure D-6. Incident and reflected light readings after coating hangar, coating age 6 months (overcast, 29 January 1973).

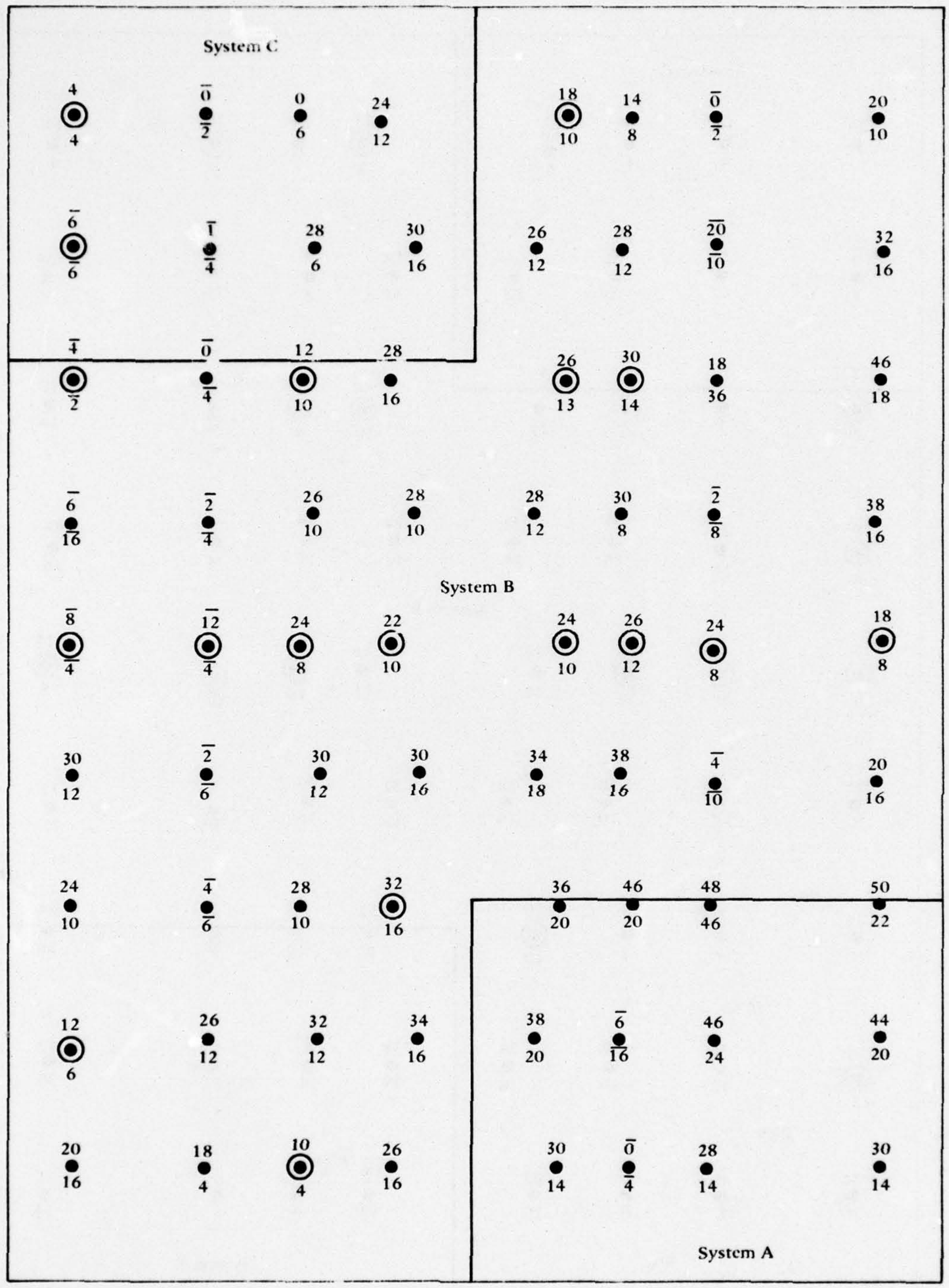

Figure D-7. Incident and reflected light readings after coating hangar deck, coating age 6 months (30 January 1973).

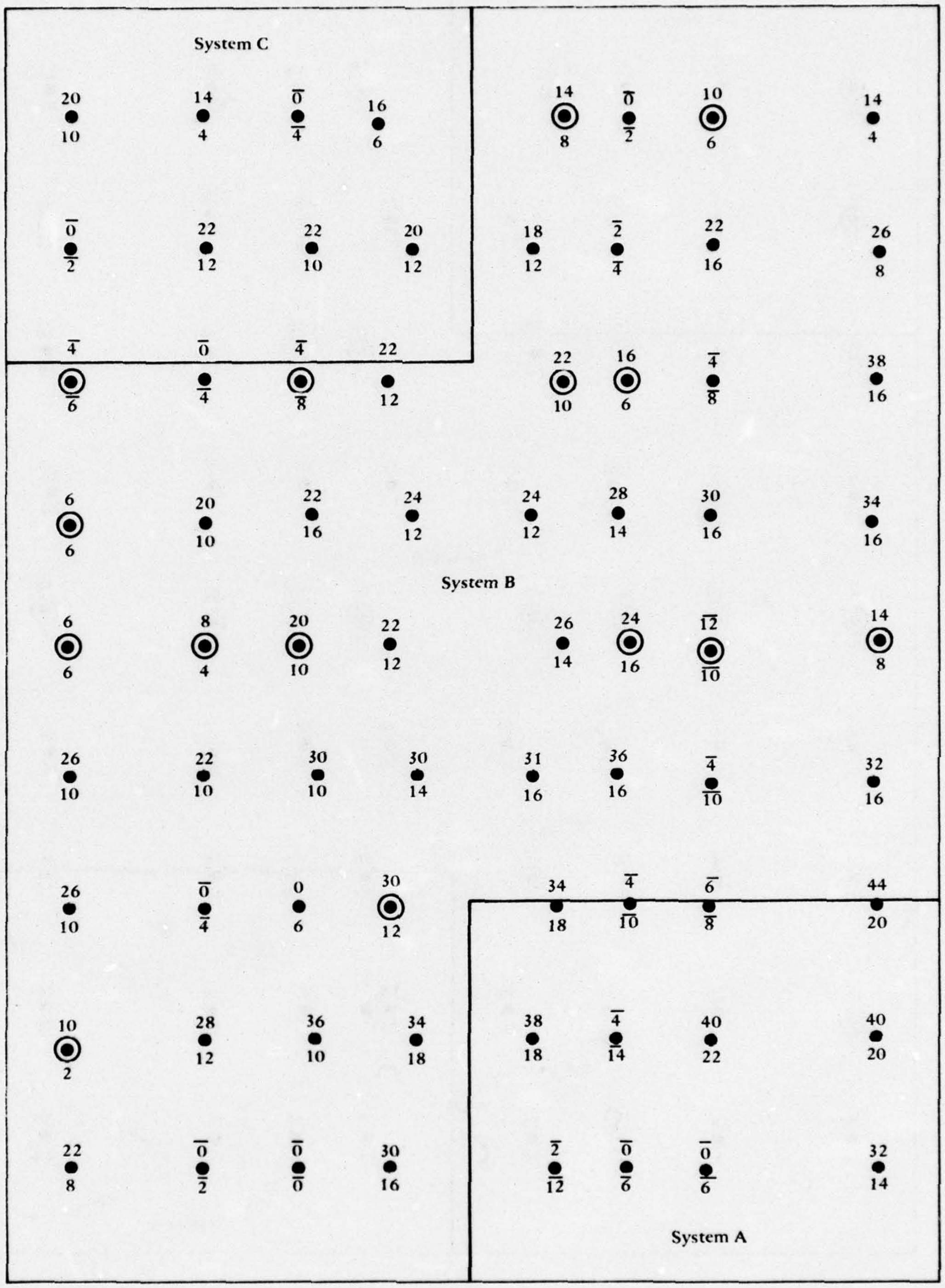

Figure D-8. Incident and reflected light readings after coating hangar deck, coating age 9 months (26 April 1973).

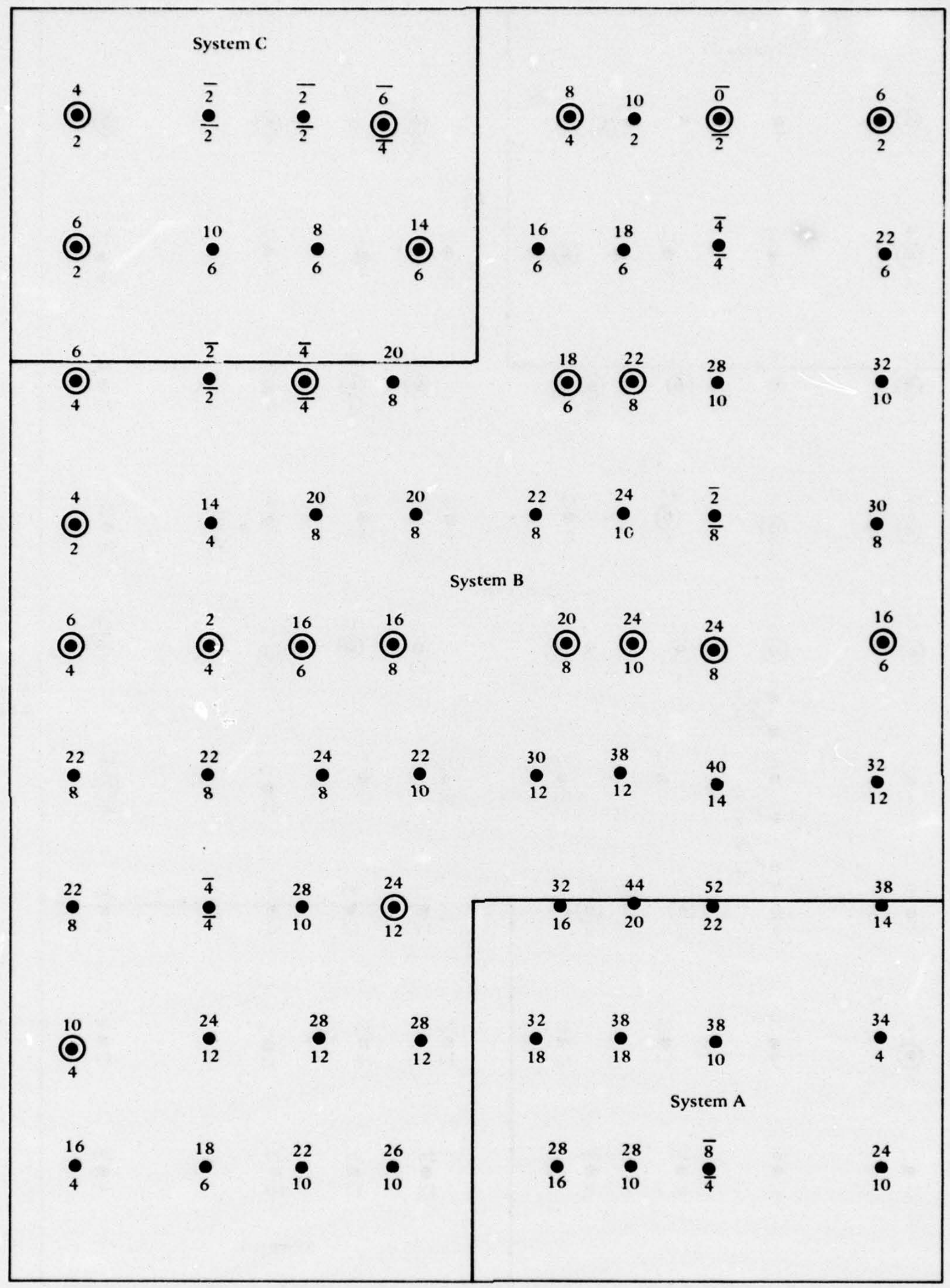

Figure D-9. Incident and reflected light readings after coating hangar deck, coating age 15 months (29 October 1973).

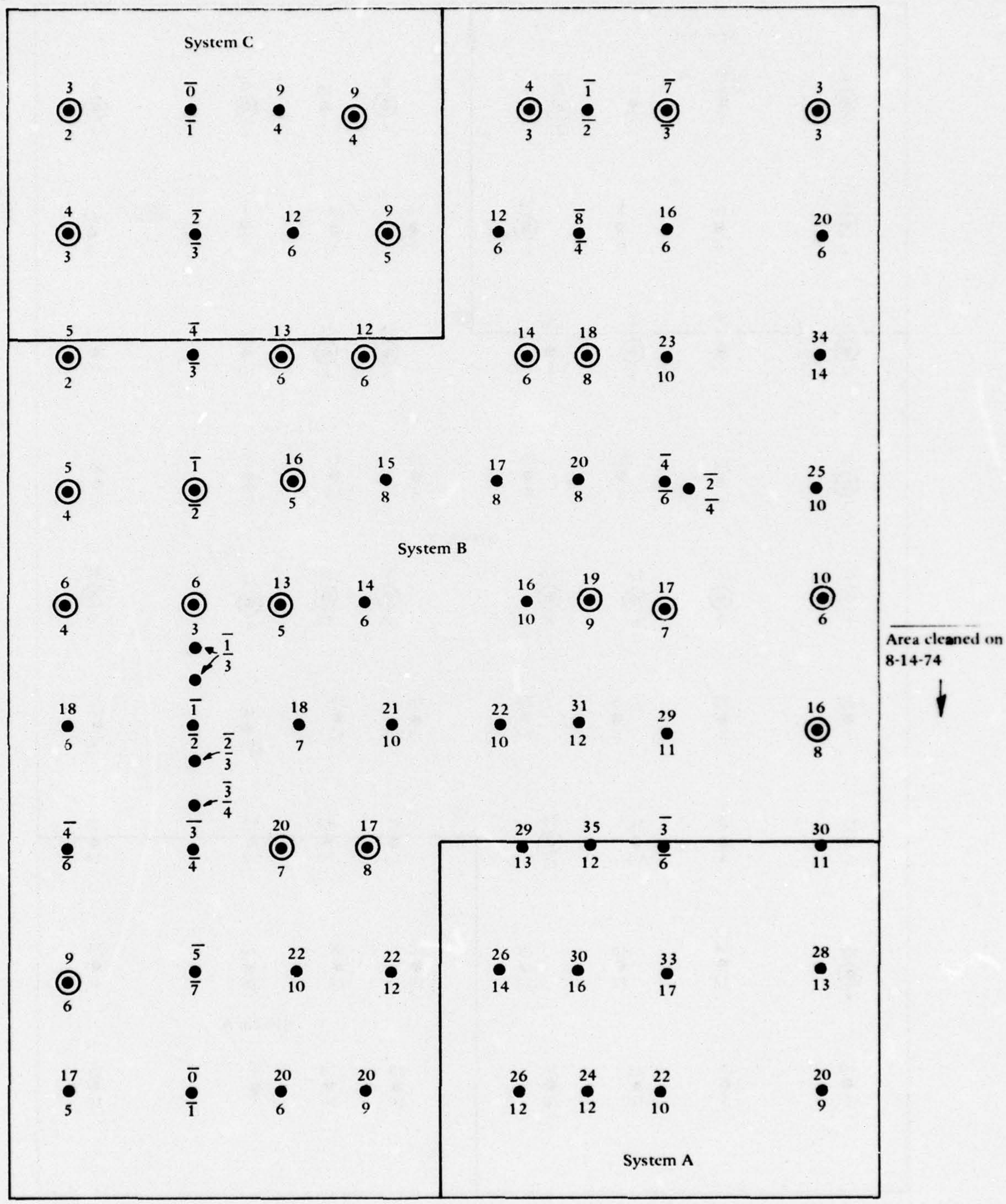

Figure D-10. Incident and reflected light readings after coating hangar deck, coating age 24 months (13 August 1974, before cleaning).

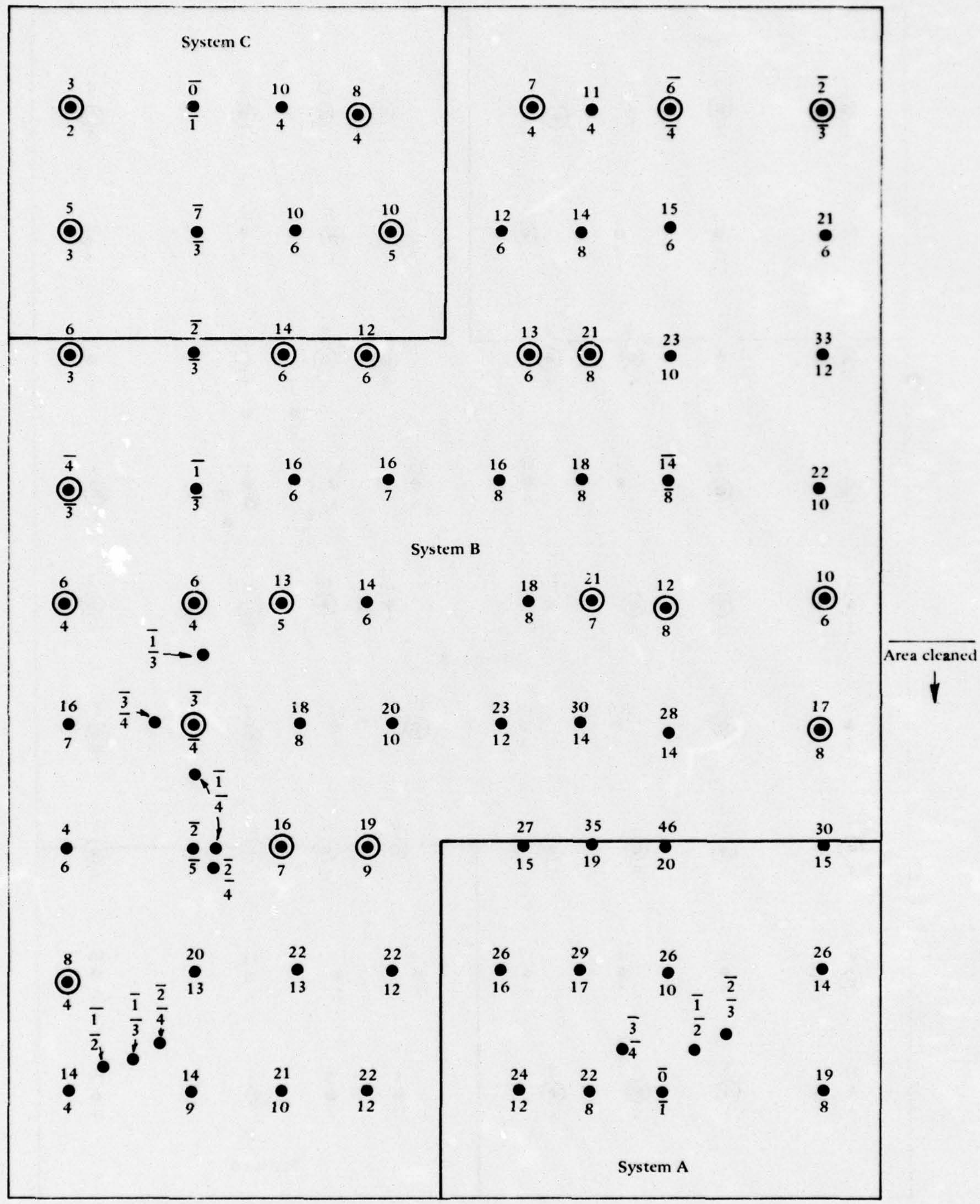

Figure D-11. Incident and reflected light readings after coating hangar deck, coating age 24 months (14 August 1974, after cleaning).

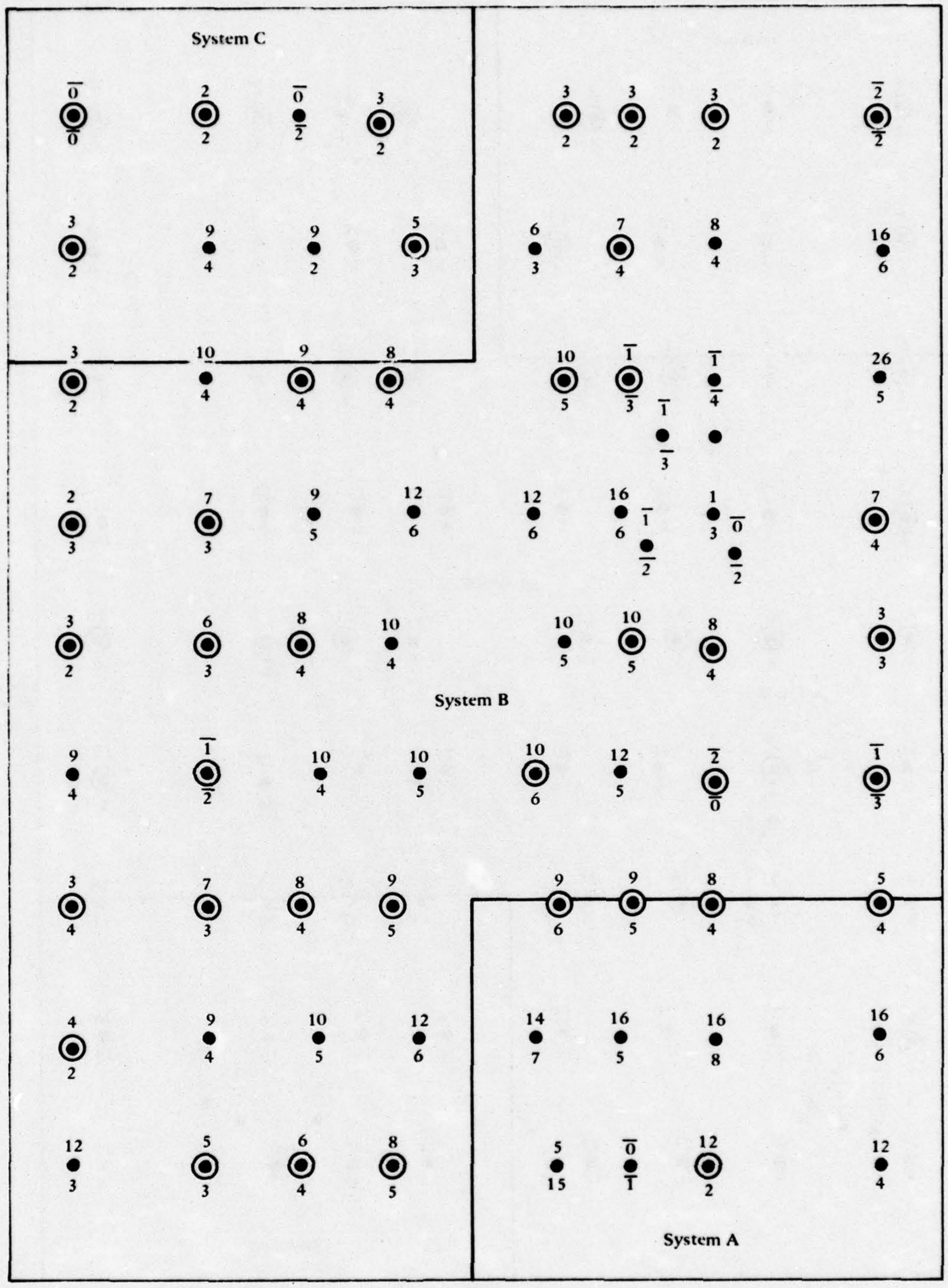

Figure D-12. Incident and reflected light readings after coating hangar deck, coating age 36 months (6 August 1975).

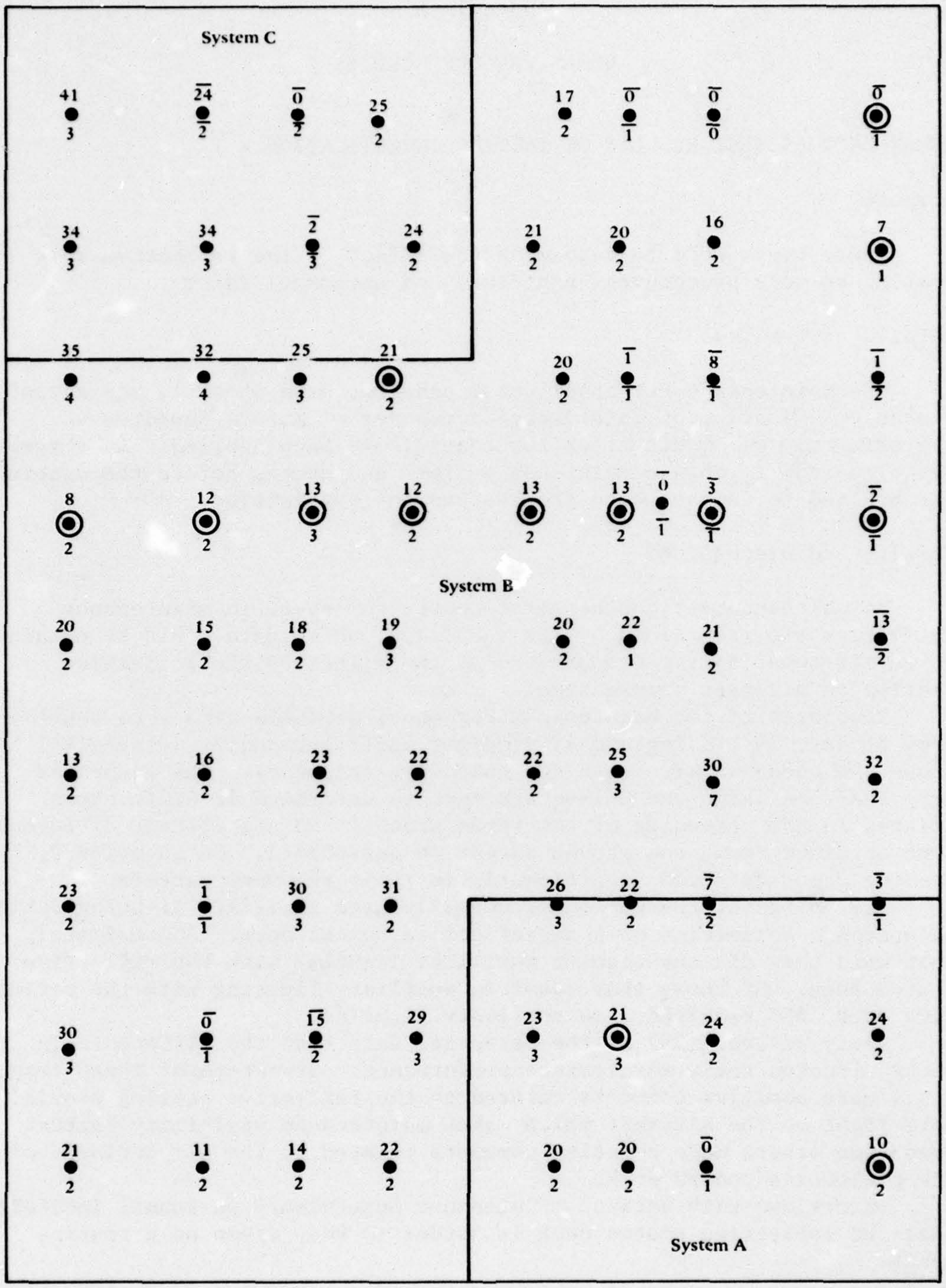

Figure D-13. Incident and reflected light readings of uncoated control deck C-2 (6 August 1975).

Appendix E

HUMAN FACTORS STUDIES

HUMAN FACTORS TEST RESULTS OF INITIAL INVESTIGATION - I

Purpose

These tests were to determine the effect of the reflective deck coating on work procedures, patterns, and personnel safety.

Details of the Test

The Maintenance Personnel Questionnaire, Data Sheet 1, was administered to 101 aviation maintenance personnel of Attack Squadron 42 approximately one month after the coating had been applied. An attempt was also made to obtain maintenance times and errors before the coating was applied to compare with those after the application.

Results and Discussion

No maintenance times or error counts for specific maintenance activities are maintained by the squadrons, so no data could be obtained to permit quantitative comparisons of the effect of the reflective coating on aircraft maintenance.

Responses to the Maintenance Personnel Questionnaire were obtained from 56 day, 34 evening and 11 midnight shift personnel. Figure E-1 shows the questionnaire with the composite responses. The responses were analyzed using the CHI-square test to determine if differences existed in the responses of the three groups. No significant differences were obtained among the groups except on question 2. On question 2, the evening group differed significantly in their response pattern.

Two-thirds of the personnel normally used auxiliary lighting during maintenance activities on a nonreflective coated deck. Approximately half said they did not require auxiliary lighting with the reflective coated deck. Of those that required auxiliary lighting with the reflective deck, 65% required less auxiliary lighting.

Forty percent (38) of the personnel felt that the difference in decks affected their maintenance performance. Seventeen of these respondents made positive comments related to the reflective coating providing more light on the aircraft which makes maintenance visibility better. Seventeen others made negative comments related to the slipperiness of the reflective coated deck.

Interviews with various maintenance supervisory personnel indicated that the reflective coated deck is harder to keep clean on a routine basis.

Conclusions

Based on responses to the questionnaire, the following conclusions are made:

1. The reflective coating requires less auxiliary lighting when performing aircraft maintenance.

2. The reflective deck and sidewall coating does not create any undesirable glare.

3. Regular concrete is easier to keep clean on a routine basis; however, the reflective coated deck is easier to clean following an oil or hydraulic fluid spill.

4. The reflective coated deck (plain) is harder to walk on when wet or oily.

5. Water spills are more easily seen on regular concrete; however, oil, hydraulic fluid and grease are more easily seen on the reflective coated deck.

6. There is a general preference for the reflective coated deck.

DATA SHEET 1

MAINTENANCE PERSONNEL QUESTIONNAIRE

NAME:____________________ RATE: ____________ DATE:________

AIRCRAFT TYPE:__________________

The purpose of this questionnaire is to get your opinions about various aspects of the reflective coating so that a thorough evaluation can be made.

1. When performing maintenance on an aircraft in a regular hangar, do you normally require auxiliary lighting?

Yes 67 No 34

2. When performing maintenance on an aircraft in a hangar with a reflective coating, do you normally require auxiliary lighting?

Day and mid evening

Yes 37/12 No 28/22

3. If you answered YES to question 2, what is the difference in amount of auxiliary lighting required with the reflective coated hangar?

More 4 Less 37 Same 14

4. Does the reflective deck or sidewall coating create any undesirable glare?

Yes 15 No 83

5. Which deck is easier to keep clean on a routine day-to-day basis?

Regular Concrete 59 Reflective Coated (Plain) 21

Reflective Coated (non-skid) 18 Both 1

6. Which deck is easier to clean up following an oil or hydraulic fluid spill?

Regular Concrete 44 Reflective Coated (Plain) 36

Figure E-1. Reproduction of questionnaire with results after first questioning.

DATA SHEET 1 continued

6. continued

Reflective Coated (non-skid) 14

7. Which deck is harder to walk on when wet or oily?

Regular Concrete 9 Reflective Coated (Plain) 66

Reflective Coated (non-skid) 23

8. On which type of deck is it easier to see and avoid?

	Regular Concrete	Reflective Coated (Plain)	Both	Reflective Coated (non-skid)
a. Water?	87	2	3	3
b. Oil spills?	22	38	11	28
c. Hydraulic fluid?	14	41	13	31
d. Grease?	11	45	13	30

9. Do you feel that the difference in decks has any effect on your maintenance performance?

No 57 Yes (explain) 38

10. Which deck do you prefer for performing aircraft maintenance?

Regular Concrete 41 Reflective Coated (Plain) 8

Reflective Coated (non-skid) 46

11. In general, which deck do you prefer?

Regular Concrete 35 Reflective Coated (Plain) 9

Reflective Coated (non-skid) 44

Figure E-1 continued

HUMAN FACTORS TEST RESULTS OF FINAL INVESTIGATION - II

Purpose

These tests were designed as a follow-up evaluation of the effect of reflective deck coating on work procedures, patterns and personnel safety.

Details of the Test

The Data Sheet 1, Maintenance Personnel Questionnaire (Figure E-2) was administered to 101 aviation maintenance personnel of Attack Squadron 42 in August 1972. The questionnaire was given approximately one month after a reflective deck coating had been applied. The questionnaire was administered again in January 1974 to 72 maintenance personnel of the same squadron. Only maintenance personnel who had previous experience working on regular concrete decks were asked to complete the second questionnaire.

Responses to the questionnaire were obtained from 43 day, 20 evening and 9 midnight shift personnel. This compares with 56 day, 34 evening and 11 midnight personnel who responded to the first questionnaire. Figure E-2 shows the latest questionnaire with its composite responses.

Dispensary records of accidental injuries (Form 5ND-GEN-6310/1) occurring in hangar bay areas from January 1971 to August 1972 were compared with injuries occurring from August 1972 through February 1974. Records were reviewed to determine if the reflective deck coating could have altered the frequency of injuries such as slips and falls.

Results and Discussion

Responses were analyzed using the Bonferroni CHI-square statistic to determine if (1) there were differences in the responses between the three shifts, and (2) if the responses to the most recent questionnaire differed from those of the first.

No significant differences were found between the three shifts in responses to the questionnaire. However, a significant difference concerning ease of cleaning decks (Questions 5 and 6) was found between the responses of the 1972 group and those of the 1974 group. This includes routine cleaning as well as cleaning of hydraulic fluids and oil spills. The 1972 group indicated it was easier to clean regular concrete while the 1974 group felt that reflective coated decks (plain) were easier to clean.

The shift in opinion about reflective coated decks (plain) being easier to clean than regular concrete most likely reflects increased familiarity with the reflective coating. It is possible that the 1972 group showed a preference for regular concrete simply because the maintenance personnel were accustomed to routinely working on such surfaces.

As work experience was gained with the new deck treatment, a change in attitudes was suggested by increased preference for the reflective coating. This change is readily explained. The smoother surface of the plain reflective coating is easier to clean because it does not retain grease and grime as do the textured finishes of concrete and non-skid reflective coated surfaces.

Both groups (1972 and 1974) agreed (in Question 8) that water is easiest to see and avoid on regular concrete. However, on reflective coated decks (plain and non-skid), water is judged more difficult to see than oil spills, hydraulic fluid and grease. Water is easier to see on regular concrete because it darkens the surface on contact whereas the light background and low contrast of reflective coatings make it less visible.

Roughly 60% of the 1974 respondents felt their performance was not affected by the different surface coatings. This is basically the same as for the 1972 group. Those who did report a difference were generally enthusiastic about the reflective coatings. They considered visibility to be improved under all conditions so that many jobs could be completed without the aid of additional light sources. This seemed to help shorten some maintenance tasks. Dropped objects such as screws and bolts were judged to be easier to detect, as well as hydraulic fluids and oil spills. However, almost half of those men reporting favorable experiences also felt that reflective coatings are very slippery when wet and correspondingly hazardous.

To determine if the likelihood of injury was greater with the reflective coated deck, injury reports maintained at the Oceana Dispensary for the period January 1971 through February 1974 were reviewed. There were no reports of injury resulting from slips and falls on the hangar bay deck. It is not known if the finding of zero injuries was due to the fact that spillage on reflective coated decks had no appreciable effect on their slipperiness or whether it was due to the workers being more cautious. Observation of routine maintenance activities would most likely provide the answer.

Conclusions

Based on analysis of the responses to the questionnaire, the following conclusions are made:

1. Reflective coated decks were judged easier to keep clean on a daily basis and following oil and hydraulic spills. This represents a shift in preference from regular concrete, as indicated on the first administration.

2. Water continues to be judged easier to see and avoid on regular concrete while oil spills, hydraulic fluid and grease are easier to see on reflective coated decks.

3. There is a greater preference for reflective coatings with non-skid than for reflective coatings (plain) or regular concrete. The frequency of responses in favor of reflective coatings (non-skid) is greater for the 1974 group than for the first administration.

4. The remaining conclusions drawn in the previous test report remain unchanged.

DATA SHEET 1

MAINTENANCE PERSONNEL QUESTIONNAIRE

NAME:____________________________ RATE: ________________ DATE__________

AIRCRAFT TYPE:_________________________

The purpose of this questionnaire is to get your opinions about various aspects of the reflective coating so that a thorough evaluation can be made.

1. When performing maintenance on an aircraft in a regular hangar, do you normally require auxiliary lighting?

Yes 45 No 27

2. When performing maintenance on an aircraft in a hangar with a reflective coating, do you normally require auxiliary lighting?

Yes 28 No 44

3. If you answered YES to question 2, what is the difference in amount of auxiliary lighting required with the reflective coated hangar?

More 4 Less 16 Same 8

4. Does the reflective deck or sidewall coating create any undesirable glare?

Yes 6 No 66

5. Which deck is easier to keep clean on a routine day-to-day basis?

Regular Concrete 16 Reflective Coated (Plain) 49

Reflective Coated (non-skid) 6

6. Which deck is easier to clean up following an oil or hydraulic fluid spill?

Regular Concrete 11 Reflective Coated (Plain) 51

Figure E-2. Reproduction of questionnaire with results after 18-month use of coated floors.

DATA SHEET 1 continued

6. continued

Reflective Coated (non-skid) 10

7. Which deck is harder to walk on when wet or oily?

Regular Concrete 3 Reflective Coated (Plain) 63

Reflective Coated (non-skid) 7

8. On which type of deck is it easier to see and avoid?

	Regular Concrete	Reflective Coated (Plain)	Both	Reflective Coated (non-skid)
a. Water?	56	2	13	1
b. Oil spills?	19	13	39	1
c. Hydraulic fluid?	15	12	44	1
d. Grease?	13	12	45	1

9. Do you feel that the difference in decks has any effect on your maintenance performance?

No 41 Yes (explain) 31

10. Which deck do you prefer for performing aircraft maintenance?

Regular Concrete 18 Reflective Coated (Plain) 15

Reflective Coated (non-skid) 39

11. In general, which deck do you prefer?

Regular Concrete 24 Reflective Coated (Plain) 14

Reflective Coated (non-skid) 34

12. Did you fill out a questionnaire like this last year?

Yes 18 No 53

Figure E-2 continued

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NAVFACENGCOM - WEST DIV. 408, San Bruno CA; AROICC, Contracts, Twentynine Palms CA; AROICC, Point Mugu CA
NAVHOSP LT R. Elsbernd, Puerto Rico
NAVOCEANO Code 1600
NAVRADRECFAC PWO, Kami Seya Japan
NAVSECGRUACT PWO, Edzell Scotland; PWO, Puerto Rico
NAVSHIPYD Code 440, Norfolk; Code 450, Charleston SC; Library, Portsmouth NH; PWO
NAVSTA CO; Engr. Dir., Rota Spain; Maint. Cont. Div., Guantanamo Bay Cuba; PWD/Engr. Div, Puerto Rico; PWO, Puerto Rico; ROICC, Rota Spain
NAVSUPPACT Maint. Div. Dir/Code 531, Rodman Canal Zone; Plan/Engr Div., Naples Italy
NAVWPNCEN PWO (Code 70), China Lake CA
NAVWPNSTA Maint. Control Dir., Yorktown VA; PWO
NAS CO, Guantanamo Bay Cuba; Code 18700, Brunswick ME; Code 18E (ENS P.J. Hickey), Corpus Christi TX; PWD (ENS E.S. Agonoy), Chase Field, Beeville TX; PWD (LT W.H. Rigby), Guantanamo Bay Cuba; PWD (M.B. Trewitt), Dallas TX; PWD, Maintenance Control Dir., Bermuda
NATIONAL BUREAU OF STANDARDS B-348 BR (Dr. Campbell), Washington DC
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NAVACT PWO, London UK
NAVACTDET PWO, Holy Lock UK

NAVAVIONICFAC PWD Deputy Dir. D/701, Indianapolis, IN
NAVBASE Code 111 (A. Castronovo), Philadelphia PA
NAVCOMMSTA PWO; PWO, Norfolk VA
NAVCONSTRACEN CO (CDR C.L. Neugent), Port Hueneme, CA
NAVEODFAC Code 605, Indian Head MD
NAVFACENGCOM Code 0453 (D. Potter); Code 1023 (T. D. Stevens), Alexandria VA
NAVFACENGCOM - CHES DIV. Code 101; Code 402 (R. Morony); Code 403 (H. DeVoe); Contracts, ROICC, Annapolis MD
NAVFACENGCOM - NORTH DIV. (Boretsky); Code 09P (LCDR A.J. Stewart); Code 1028, RDT&ELO, Philadelphia PA; Code 114 (A. Rhoads); ROICC, Contracts, Crane IN
NAVFACENGCOM - WEST DIV. 102; 112; Codes 09PA; O9P/20
NAVFACENGCOM CONTRACTS Bethesda, Design Div. (R. Lowe) Alexandria VA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, PI; OICC/ROICC, Balboa Canal Zone; ROICC (LCDR J.G. Leech), Subic Bay, R.P.; ROICC, Pacific, San Bruno CA; TRIDENT (CDR J.R. Jacobsen), Bremerton WA 98310
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NAVSUPPACT CO, Brooklyn NY; CO, Seattle WA
NAVWPNCEN ROICC (Code 702), China Lake CA
NAVWPNSTA Code 092A (C. Fredericks) Seal Beach CA
NCBC CEL (CAPT N. W. Petersen), Port Hueneme, CA; CEL AOIC; Code 10; Code 400, Gulfport MS; PW Engrg, Gulfport MS; PWO (Code 80); PWO, Davisville RI
NCBU 411 OIC, Norfolk VA
NCR 20, Commander
NMCB 133 (ENS T.W. Nielsen); 5, Operations Dept.; 74, CO; Forty, CO; THREE, Operations Off.
NRL Code 8441 (R.A. Skop), Washington DC
NROTCU Univ Colorado (LT D R Burns), Boulder CO
NSC Code 700; Code 703 (M. Miller), Pearl Harbor HI; E. Wynne, Norfolk VA
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SPCC PWO (Code 120 & 122B) Mechanicsburg PA
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UCT TWO OIC, Port Hueneme CA
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